UNCLASSIFIED

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

# TECHNICAL MEMORANDUM

REPORT NO: NAWCADPAX--96-268-TM

COPY NO. 458

# SITUATIONAL AWARENESS GUIDELINES

8 January 1997

Approved for public release; distribution is unlimited.



UNCLASSIFIED

DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

NAWCADPAX--96-268-TM
8 January 1997

This Technical Memorandum supports the requirements of AIRTASK A272272C/008C/5E21940004 and AIRTASK A272272C/008C/6E21940004.

**PREPARED BY:**

Karen T. Garner 8 Jan 97

KAREN T. GARNER / DATE

Thomas J. Assenmacher 8 January 1997

THOMAS J. ASSENMACHER (ARINC, Inc.) / DATE

**RELEASED BY:**

Donald J Harris

DONALD J. HARRIS / DATE
Head, Crew Systems Engineering Division
Naval Air Warfare Center Aircraft Division

| REPORT DOCUMENTATION PAGE | | | | Form Approved OMB No. 0704-0188 |
|---|---|---|---|---|



| 1. AGENCY USE ONLY *(LEAVE BLANK)* | 2. REPORT DATE<br>8 January 1997 | 3. REPORT TYPE AND DATES COVERED<br>Technical Memorandum |
|---|---|---|
| 4. TITLE AND SUBTITLE<br>Situational Awareness Guidelines | | 5. FUNDING NUMBERS |
| 6. AUTHOR(S)<br>Karen T. Garner<br>Thomas J. Assenmacher (ARINC, Inc.) | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>Naval Air Warfare Center Aircraft Division<br>22347 Cedar Point Road Unit #6<br>Patuxent River, Maryland 20670-1161 | | 8. PERFORMING ORGANIZATION REPORT NUMBER<br>NAWCADPAX--96-268-TM |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>Naval Air Systems Command<br>1421 Jefferson Davis Highway<br>Arlington, Virginia 22243-0700 | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER |
| 11. SUPPLEMENTARY NOTES | | |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT<br>Approved for Public Release; Distribution is Unlimited. | | 12b. DISTRIBUTION CODE |

13. ABSTRACT *(Maximum 200 words)*

In an effort to improve operator Situational Awareness (SA), the SA Integrated Product Team (IPT), sponsored by the Electronic Warfare Advanced Technology (EWAT) Program, developed Situational Awareness Guidelines. The guidelines were developed based on lessons learned and research of current and emerging technologies. Guidelines, standards, studies, and experiments were researched, synthesized, and compiled to form this document. The guidelines can be applied to most programs for improved aircrew-system integration. They provide human-focused ways to improve aircrew SA.

| 14. SUBJECT TERMS | | | 15. NUMBER OF PAGES |
|---|---|---|---|
| Situational Awareness | Display Formatting | System Features | 141 |
| Crew-System Integration | Information Coding | Advanced Technology | 16. PRICE CODE |
| Human Factors | Environmental Stressors | Guidelines | |
| Enhancement Coding | Auditory Coding | | |
| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
| Unclassified | Unclassified | Unclassified | SAR |

## SUMMARY

In an effort to improve operator Situational Awareness (SA), the SA Integrated Product Team (IPT), sponsored by the Electronic Warfare Advanced Technology (EWAT) Program, developed Situational Awareness Guidelines. The guidelines were developed based on lessons learned and research of current and emerging technologies. Guidelines, standards, studies, and experiments were researched, synthesized, and compiled to form this document. A comprehensive list of references supporting the guidelines is included in the appendix. The guidelines can be applied to most programs for improved aircrew-system integration. They provide human-focused ways to improve aircrew SA. Implementing the guidelines during system development will result in efficient, effective information presentation to crewmembers, thus improving situational awareness.

## ACKNOWLEDGMENTS

Sincere thanks to researchers, engineers, and crewmembers working diligently to improve situational awareness. Please consider it a compliment that we referenced your work in this compilation of guidelines.

Thanks to Ms. Ranjana Sahai for researching and contributing to the environmental section of the guidelines. Thanks also to Mr. Jim Rodriguez for assisting with the guidelines format.

# CONTENTS

## BACKGROUND

1. The Situational Awareness (SA) Integrated Product Team (IPT), sponsored by the Electronic Warfare Advanced Technology (EWAT) Program, was formed because fleet tactical aircraft aviators consistently rank SA as a critical mission concern. Although many definitions are published, we have adopted the following definition of SA:

> **"Operator SA comprises detecting information in the environment, processing the information with relevant knowledge to create a mental picture of the current situation, and acting on this picture to make a decision or explore further."**

2. The nature of the battle scene of the 1990's and beyond makes the lack of adequate SA the paramount mission concern of many warfighters. Even third world opponents use highly mobile and lethal forces against airborne targets. To counter the threat, the tactical aircraft weapon system must identify, avoid, or defeat surface and air-to-air threats. Threat response includes accurate, effective weapons delivery with maximum efficiency. Improved SA is the key to providing maximum efficiency. The design of data-to-information processing and presentation of information to the aircrew are among the most important factors in acquiring and maintaining SA. The Situational Awareness Guidelines (appendix A) concentrate on these areas as they relate to improving SA.

3. SA is complex and requires integrating inputs from multiple sensors which include offboard and onboard aircraft systems as well as human physiological systems. Sensor systems provide data to aircraft computers; computers process the data using algorithms and then (the tricky part) present the processed data as "information" to the aircrew who possess diversified capabilities and preferences. A 1992 Patuxent River investigation (references 1 and 2) of tactical aircraft electronic combat problems revealed a clear link between the threats encountered and crew-system integration with the various avionics/sensor systems. Clarification of this link is provided by the following example taken from the study summary:

> Current tactical EW systems lack integration and sufficient fusing/merging/ correlation of sensor data. They can only operate because the operator is in the loop, using multiple independent equipments, responding to threats keyed by radar warning receivers and visual sightings. The aircrew tends to be overworked, responding to threats at the wrong time, overusing limited expendables, and often giving no defensive response since some missiles are never detected.

## PURPOSE

4. The primary purpose of the Situational Awareness Guidelines is to provide structure for acquisition and program managers, as well as system developers, to apply during the development cycle that will result in more efficient and effective information presentation for the operator.

## DESCRIPTION

5. The guidelines are organized into seven functional areas: 1.0 System Features, 2.0 Display Formatting, 3.0 Information Coding, 4.0 Enhancement Coding, 5.0 Auditory Coding, 6.0 Environmental Stressors, and 7.0 Advanced Technology. Each functional area is further broken into categories. For example, 1.1 Display Processing/Control, 1.2 Display Size/Viewing Distance, and 1.3 Latency are categories discussed in the 1.0 System Features functional area. A Rationale, explaining why the items are important to situational awareness, introduces each category. The specific guidelines follow the rationale. In the Advanced Technology categories 7.4 Three-Dimensional Audio and 7.5 Sensor/Data Fusion, we use the term "Design Consideration" vice "Guideline" because of the emerging nature of these technologies. Supporting information, including references, examples, and assessment methods, follow the guidelines.

## METHOD

6. The guidelines were developed based on lessons learned and research of current and emerging technologies. The 1992 Patuxent River investigation of tactical aircraft electronic combat problems (references 1 and 2) was the impetus for this effort and was referred to frequently in an effort to "answer" some of the interface issues documented in that report. Research of the interface guidelines consisted of gleaning appropriate material from numerous Human Computer Interface documents, including such diverse sources as the Engineering Data Compendium, Nuclear Regulatory Commission Advanced Human-System Interface Design Review Guidelines, NASA Human-computer Interface Guidelines, and various military standards, human factors studies and experiments, and Internet resources.

## CONCLUSION

7. These guidelines, being intuitive and generic, can be applied to most programs for improved aircrew-system integration. They provide human-focused ways to improve aircrew SA. By applying these guidelines, the human operator will be better integrated into the complete weapon system. The information presented here will guide system designers in developing designs for optimum information conversion and transfer, matching aircrew requirements to mission demands. This, in turn, will aid aircrew in achieving and maintaining SA, leading to mission success and higher survival rates.

## RECOMMENDATION

8. Apply the Situational Awareness Guidelines when upgrading aircraft and developing future tactical aircraft, including cockpit upgrades and single subsystem replacement efforts.

## REFERENCES

1. Garner, Karen T., Rodriguez, James A., Albright, CDR Daphne G., Investigation of Tactical Aircrew Electronic Warfare Crew-System Integration Issues, Flight Test and Engineering Group, Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland, Technical Report SY-72R-92, of 14 Dec 1992.

2. Garner, Karen T., Rodriguez, James A., Albright, CDR Daphne G., Addendum to SY-72R-92, Investigation of Tactical Aircrew Electronic Warfare Crew-System Integration Issues (U), Flight Test and Engineering Group, Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland, Technical Report SY-S73R-92, of 4 Mar 1993.

THIS PAGE INTENTIONALLY LEFT BLANK

# APPENDIX A
# SITUATIONAL AWARENESS GUIDELINES

# CONTENTS

## Introduction

### Situational Awareness Interface Guidelines

"Probably the first thing that can be done to help pilots achieve SA in a demanding environment is to improve the Pilot Vehicle Interface so that the required information can be gleaned with a minimum amount of workload. Unnecessary workload may be typically required to: (1) find needed information somewhere in a maze of screens available, (2) acquire information from a given display format, filtering out unneeded, competing information, and (3) integrated low level data or interpolate data to derive the SA information that is needed, in the form it is needed in, for decision making."
(Mica Endsley; Human Capabilities and Limitations in Situation Awareness, AGARD CP-520, 19-22 October, 1992)

System automation and advanced interface design are rapidly evolving and are becoming increasingly important in the development of Tactical Situational Awareness. These guidelines address the following concerns in developing new systems or enhancements to existing systems in tactical aircraft.

**Crewmember Concerns Regarding Automation and Advanced Interfaces**

- Maintaining sufficient alertness to perform adequately the activities which an automated system cannot undertake.

- Maintaining basic aeronautical skills.

- Reduction in system understanding.

- Reduction in job satisfaction.

- Crewmember complacency, lack of vigilance and boredom.

- Making the transition between automated and nonautomated aircraft.

- Placing too much trust in automation - lack of dependence on airmanship.

- Over reliance on automation - inadequate preparation to deal with automatic system failures.

- Loss of sense of reality - false perception of reality as that of the input and display devices.

- Reluctance to take over from an automated system, despite evidence of malfunctions.

- Lack of challenge brought about by automation assuming more and more crew tasks and being removed from the control loop.

**Design Concerns Regarding Automation and Advanced Interfaces**

- Flat panel displayed legends that vary according to the current mode of operation.

- Multifunction switches that reduce the number of switches in the cockpit, but introduce complexity and the need for greater training.

- Devices or system designs that limit the crewmember's ability to respond when the unexpected occurs.

- Flight management systems with cumbersome interaction, and where improper programming can introduce error.

- High false alarm rates that lead to failure to respond to genuine alarms.

- Inadequately designed input devices which result in input errors.

- Automation that reduces the number of small errors but invites new forms of operational errors.

- Premature introduction of equipment.

- Fault intolerant systems.

- Technology that allows silent failures.

- Systems that are too complex and allow crewmembers to be surprised by automatic features.

**Information Management Concerns Regarding Automation and Advanced Interfaces**

- The amount of information displayed is simpler, but may be less accessible. The crewmember must learn how to access information.

- Designers rather than crewmembers may determine what information is essential.

- Too much programming and head down time takes place at low altitude, and during times of intense tactical activity.

- Lack of situational awareness in identifying and correcting the problem when an automated system fails.

**Acronyms**

| | |
|---|---|
| 3-D | Three-Dimensional |
| AGARD | Advisory Group for Aerospace Research and Development |
| AWACS | Airborne Warning and Control System |
| CBR | Chemical, Biological, Radiological |
| $cd/m^2$ | Candela per Square Meter |
| CRT | Cathode Ray Tube |
| CSERIAC | Crew System Ergonomics Information Analysis Center |
| cm | Centimeter |
| DVI | Direct Voice Input |
| dB | Decibel |
| deg | degree(s) |
| EEG | Electro-Encephalograph |
| ET | Effective Temperature |
| FAGT | Full coverage Anti-G Trousers |
| fc | Foot Candles |
| FCS | Flight Control System |
| ft-L | Foot-Lambert |
| GLOC | G-induced Loss Of Consciousness |
| HCI | Human Computer Interface |
| HMD | Helmet Mounted Display |
| HOTAS | Hands On Throttle And Stick |
| HSCT | High-Speed Civil Transport |
| HUD | Head Up Display |
| Hz | Hertz (cycles) |
| ICS | Inter-Communications System |
| IFR | In-Flight Refueling |
| IVR | Interactive Voice Response |
| in. | Inch |
| LCD | Liquid Crystal Display |
| MAA | Minimum Audible Angle |
| mm | Millimeter |
| mrad | Milliradian |
| msec | Microsecond |

| | |
|---|---|
| NASA | National Aeronautics and Space Administration |
| NRC | Nuclear Regulatory Commission |
| NVIS | Night Vision Imaging Systems |
| PALE | Pelvis And Leg Elevating |
| PBG | Positive pressure Breathing for G protection |
| REM | Rapid Eye Movement |
| RPD | Recognition-Primed Decision |
| SAGAT | Situational Awareness Global Assessment Technique |
| SART | Situational Awareness Response Technique |
| S/N | Signal-to-Noise Ratio |
| VRD | Virtual Retinal Display |
| VSI | Vertical Speed Indicator |

**Functional Area: 1.0 System Features**

1.1 Display Processing/Control
1.2 Display Size/Viewing Distance
1.3 Latency

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **1.0 System Features** **Category:** **1.1 Display Processing/Control**

**Rationale:**

Information processing and presentation to the crewmember has a direct bearing on how well the information is perceived, assimilated, and acted upon. Information should be clear, concise, devoid of clutter and require little cognitive effort on the part of the crewmember. Crewmembers should be able to specify the information to be displayed and select the format in which it is presented.

**Guidelines:**

1.1.1 Displays should present the simplest information consistent with their function, information irrelevant to the task should not be displayed, and extraneous text and graphics should not be present.

1.1.2 All information required by the crewmember during a transaction should be available on the current display.

1.1.3 When displays are partitioned into multiple pages, function/task related information items should be displayed together on one page.

1.1.4 Crewmembers working with multipage displays should be provided with a page location reference within the display sequence.

1.1.5 Information depicted on a display should be grouped according to obvious principles (e.g., by task, system, function, sequence, etc.) based on crewmember requirements in performance of the ongoing task.

1.1.6 Crewmembers should be able to control the amount, format, and complexity of displayed information to meet task requirements.

1.1.7 Input and control devices provided for interacting with the display should be appropriate for crewmember task requirements and environment.

1.1.8 Visual or auditory feedback should be provided to indicate that a display input has been registered, and that the system response or action is obvious.

1.1.9 Crewmembers should be able to tailor information displays by controlling information selection, coverage, updating, and suppression and should be able to specify information for display. An easy means to return to normal display coverage should be provided.

1.1.10 Crewmembers should be able to control displayed information or enter new information when required by a task.

1.1.11 Crewmembers should not be required to accurately remember information from one display page to another.

1.1.12 Screen control locations and control options should be clearly and appropriately indicated.

1.1.13 When a crewmember is prompted by the system for a parameter, the default value should be shown.

1.1.14 A consistent and easy means of moving through information should be provided by windowing, panning, paging, or scrolling.

1.1.15 Paging versus scrolling labels should be consistently distinct and unambiguous. Display framing should be described (e.g., in user instructions and key labels) in functional terms and wording. Spatial orientation should be avoided.

1.1.16 Provide the crewmember with a zooming capability that allows the expansion of the display of any selected area.

1.1.17 When lists of numbered items exceed one display page, items should be numbered continuously in relation to the first item on the first page.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **1.0 System Features** **Category:** **1.1 Display Processing/Control**

**References:**

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (1.1.9 through 1.1.17)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (1.1.6)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5, 1.1.6, 1.1.7, 1.1.8, 1.1.15, 1.1.16)

**Example:**

1.1.1 Displayed information should be tailored to crewmember needs, providing only necessary and immediately usable information for any transaction.

1.1.3 Relations among information sets should appear in an integrated display rather than partitioned into separate pages.

1.1.4 A typical format is to identify pages by the phrase "page x of y."

1.1.5 Fuel management displays should not be grouped with armament control displays.

1.1.6 The crewmember should be provided means to declutter targets by selecting priority levels.

1.1.7 Provide HOTAS input and control devices for use during high "g" maneuvers.

1.1.8 The use of touch screen technology to activate and change display modes and functions in high performance tactical aircraft is becoming more commonplace. When the crewmember touches an option or makes an input to the display, the option or input is highlighted to provide feedback.

1.1.15 Examples of framing in functional terms are: "forward" and "back" or "next" and "previous." Control of display framing functions might be implemented by keys marked with arrows to avoid verbal labels altogether.

1.1.16 Provide a crewmember selective zoom feature while displaying digital maps.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. (1.1.1 through 1.1.17)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 1.0 System Features** **Category: 1.1 Display Processing/Control**

**Guidelines (continued):**

1.1.18 Information (target range, bearing, speed) should be displayed long enough to be read to the level of precision required.

1.1.19 Rate of display regeneration should not exceed crewmember perceptual and information processing capabilities.

1.1.20 Changing alphanumeric information, which must be reliably or accurately read, should not be updated more often than once per second.

1.1.21 When displayed information is considered real time, changing values which are used to identify rate of change or to read gross values should not be updated faster than five times per second, nor slower than two times per second.

1.1.22 Unless directed by task, system, or mission requirements (as in tactical displays), crewmembers should be able to initiate display regeneration.

1.1.23 When information is changed via automatic processing, information updates should be temporarily highlighted or otherwise marked.

1.1.24 When displayed information is automatically updated, crewmembers should be able to "freeze" the display to examine changed information more deliberately.

1.1.25 When frozen, the display should clearly be labeled, and crewmembers should be warned if some significant information change has occurred due to subsequent processing or sensing.

1.1.26 When resuming update after display freeze, display update should resume at the current real-time point unless otherwise specified by the crewmember.

1.1.27 When needed, a prediction display extrapolating dynamic display information should be provided.

1.1.28 When displayed information is changing as a result of external events, a crewmember should be able to request automatic update (computer regeneration) of changed information and be able to control the update rate.

1.1.29 Use scrolling for searching through continuous text information; use paging for searching logically grouped information.

1.1.30 Allow the crewmember to review any active control parameter(s). Information that the crewmember must manipulate should be displayed as it becomes available.

1.1.31 When crewmember input involves frequent pointing on a display surface, the interface should be designed so that other actions (e.g., display control) are accomplished by pointing, in order to minimize shifts from one entry device to another.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 1.0 **System Features** **Category:** 1.1 **Display Processing/Control**

**References:**

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (1.1.18 through 1.1.27)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation Bedford, Massachusetts, USA, 1986. (1.1.28)

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (1.1.29)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (1.1.30)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (1.1.30, 1.1.31)

**Example:**

1.1.21 Digital altimeters and rate of climb indicators fall into this category.

1.1.23 Real time sensor data processing and information display fall into this category.

1.1.27 Projecting the position of a hostile air contact in 5 min given current bearing, velocity, altitude, etc., is an example.

1.1.28 Automatically updated threat parameter information, for example.

1.1.30 Scaling, page numbering, track-up/north-up, etc., fall into this category.

1.1.31 For example, consolidate pointing functions to the "coolie hat" switch.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. (1.1.18 through 1.1.31)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **1.0 System Features** **Category:** **1.2 Display Size/Viewing Distance**

**Rationale:**

As the size of a visual display increases, the average duration of each eye fixation decreases and the average interfixation distance increases. The optimum size of a static display subtends 9 deg of visual angle at the eye. When viewing a display <9 deg in diameter, crewmember efficiency (defined as the percentage of fixations made within the display area) decreases. Although some fixations are made in the center of the display, many occur outside the display. In larger displays, the tendency to concentrate fixations in the center of the display results in the loss of peripheral information; therefore, the larger the display, the more peripheral information is lost.

Search time is approximately proportional to the number of items present on a display. When combinations of area and density (number of background characters per degree$^2$) are chosen to give specific numbers of background characters (i.e., clutter), the major effect on search time comes from the number of background characters rather than from area or density. Density has a separate effect: for a given number of background characters, search performance is enhanced with increasing density.

The number of nontarget elements in a visual display is a primary determinant of search performance. The separate effect of density indicates that it is more efficient to search densely packed items than spaced items; close packing more than compensates for the camouflage effects of a denser display. For a given number of nontarget elements, increased density will enhance search performance. (Boff & Lincoln, 1988)

**Guidelines:**

1.2.1 Increasing display size over 9 deg may have little effect on search behavior.

1.2.2 Peripheral information in displays >9 deg may be lost because fixations are concentrated in the center of the display. Larger displays entail a lower probability that peripherally located objects will be detected.

1.2.3 The limiting grid of an overlay technique should leave surrounding areas visible if the display size is to be limited to <9 deg. The percentage of eye fixations falling outside the display markedly increases when viewing a display <9 deg in diameter.

1.2.4 When a display window is used for information scanning, ensure that the window can display more than one line of information.

1.2.5 Provide a means for quickly returning to the normal display size when zooming.

1.2.6 The minimum design viewing distance should be equal to or greater than 12 in. (30 cm). Displays which must be placed at viewing distances greater than 16 in. (40 cm) due to other considerations should be appropriately modified in aspects such as display size, symbol size, brightness ranges, line-pair spacing, and resolution.

1.2.7 Character height should subtend a minimum visual angle of 15 min (or 0.004 multiplied by the viewing distance), with a visual angle of 20 min (or 0.006 multiplied by the viewing distance) preferred. Character height should be identical for all labels within the same hierarchical level, based on the maximum viewing distance.

1.2.8 Ensure that color-coded symbols subtend a minimum of 20 min of visual arc. The designer must determine the maximum viewing distance from the display, then calculate the minimum size of the object, using the formula:

$$\text{Visual Angle (Min.)} = (57.3)\,(60)L / D$$

where L = size of the object and D = distance from the eye to the object.

1.2.9 When a displayed symbol of complex shape is to be distinguished from another symbol shape that is also complex, the visual angle of the symbol should not subtend less than 20 min of arc at the required viewing distance. Symbols that must be distinguished from other complex shapes should have a minimum of 10 resolution elements for the longest dimension of the symbol.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **1.0 System Features** **Category:** **1.2 Display Size/Viewing Distance**

**References:**

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (1.2.1, 1.2.2, 1.2.3)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation Bedford, Massachusetts, USA, 1986. (1.2.4)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (1.2.5,1.2.8)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (1.2.6, 1.2.7, 1.2.9)

**Example:**

1.2.5 Provide a means of zooming in and out from digital map displays.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the display size and viewing distances by comparing the actual display size and distances with the criteria of these guidelines. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. (1.2.1 through 1.2.9)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **1.0 System Features** **Category:** **1.3 Latency**

**Rationale:**

Modern cockpits and simulators are becoming more complex. The use of equipment such as helmet mounted displays, voice activated systems, digital moving map systems, and advanced virtual environments has increased dramatically. With this boom comes greater concerns for potential adverse effects of technology on the crewmember. One such adverse effect is system latency, which is defined as the difference in time between crewmember input to a system and the display of the system response to that particular input. System delays may reduce crewmember performance, cause errors in judgment, and, in some instances, cause motion sickness. Although system delays are composed of several factors, including sensor delay, computer processing delay, and display delay, overall system delay remains most important because it appears to affect crewmember performance most profoundly. To maintain acceptable crewmember performance, limits should be set on the maximum amount of delay allowable for the display system. Because systems vary, the recommended maximum delay levels vary as well.

**Guidelines:**

**General**

1.3.1 Where system overload or other system conditions will result in a processing delay, the system shall acknowledge the information entry and provide an indication of the delay to the crewmember.

1.3.2 Crewmember performance may be more degraded in a fixed based ground simulator mode than in an actual in-flight mode. This factor can be applied to the design of ground simulators and the design of avionics systems with delays between operator input and displayed output.

1.3.3 Total system display latency $\leq$120 msec is desired although display latency $\leq$150 msec is considered adequate.

**Head Coupled Systems**

1.3.4 To accurately compensate for the effects of eye-slaved display delay, a head-coupled system with an eye-display lag $\leq$40 msec is recommended.

1.3.5 For continuous Helmet-Mounted Display (HMD) head tracking tasks, a delay $\leq$40 msec is recommended to preserve quality performance.

**Flight Control Systems**

1.3.6 Flight Control System (FCS) lags of $\leq$100 msec are required for displacements of the pitch, roll, and yaw cockpit controls.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 1.0 **System Features** **Category:** 1.3 **Latency**

**References:**

Johns, J. B., Funk, J. D., Impact of V-22 Display Latency on Flying Qualities, Warminster, PA: Naval Air Development Center, DTIC No. AD-B161 084, 1991. (1.3.3)

So, R. H. Y., Griffin, M. J., Effect of Lags on Human Performance with Head-Coupled Simulators, Wright-Patterson Air Force Base, OH: Air Force Material Command, DTIC No. AD-A279 577, 1993. (1.3.6)

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (1.3.5)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (1.3.1, 1.3.6)

U.S. Department of Defense, Flying Qualities of Piloted Airplanes, MIL-F-8785C, 1980. (1.3.6)

Gawron, V. J., Bailey, R. E., Knotts, L. H., McMillan, G. R., Comparison of Time Delay during In-Flight and Ground Simulation, Proceedings of the Human Factors Society 33rd Annual Meeting, 1989. (1.3.2)

Best, P. S., Schopper, A. W., Effects of System Delay on Aviator-Related Performance, CSERIAC-RA-95-011, 1995. ( 1.3.1, 1.3.3, 1.3.4, 1.3.5, 1.3.6)

**Example:**

1.3.1 The hourglass symbol may be used to denote a processing delay.

1.3.3 A total delay of 120 msec could be described as 80 msec of inherent system delay plus an additional 40 msec eye coupled system delay.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Measure display latency under typical cockpit environmental and operational conditions. (3.1.1, 3.1.2, 3.1.3, 3.1.4, 3.1.6)

THIS PAGE INTENTIONALLY LEFT BLANK

**Functional Area: 2.0 Display Formatting**

2.1 Declutter
2.2 Density
2.3 Windowing

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 2.0 Display Formatting** **Category: 2.1 Declutter**

**Rationale:**

Displays easily become visually overwhelming, cluttered, and confusing when they present too much information. Human visual performance deteriorates with high density levels of graphic information. Performance deterioration may be evidenced by increased user response time and/or lowered accuracy of visual perception. The provision of options for reducing the density levels of graphic information is becoming increasingly critical in user interface design.

**Guidelines:**

2.1.1 Display sequencing may be used to reduce clutter, to reproduce temporal changes in the display, and to aid in visualizing database changes in the battlefield situation.

2.1.2 Old data points should be removed after some fixed period of time.

2.1.3. Unnecessary borders should not be used in the display.

2.1.4 If routine display of path information seems to clutter menu formats, then a map of the menu structure might be provided at user request as a HELP display.

2.1.5 Displays should be as uncluttered as possible. Display packing density should not exceed 50%. Density should be minimized for displays of critical information. Displays consisting largely of alphanumerics generally should not exceed 25% density. Displays composed largely of graphics may be more dense. The unused area should be distributed to separate logical groups, rather than having all unused area on one side. When a display contains too much data for presentation in a single frame, the display should be partitioned into separately displayable pages (multipage displays) or displayed through frames/viewports (such as scrollable windows).

2.1.6 Scales should not be cluttered with more marks than necessary for precision.

2.1.7 Use color with discretion. Too much color variation will confuse the viewer by creating clutter. (Refer to Category 3.1.)

2.1.8 Crewmembers should be able to view or declutter overlapping symbol labels and obtain additional information, including exact map coordinates, for selected symbols (e.g., by double clicking on the symbol). The intensity of the map should be adjustable so that selected portions of the map can be faded out without losing all map features. Crewmembers should be able to distinguish among symbols that represent coincident points and to obtain information that will allow them to resolve ambiguities among the symbols.

2.1.9 Provide crewmembers a means for reducing clutter while preserving essential information.

2.1.10 When zooming, combine individual symbols into fewer summary symbols to declutter the display.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 2.0 Display Formatting** **Category: 2.1 Declutter**

**References:**

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (2.1.1, 2.1.7, 2.1.9, 2.1.10)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6)

Defense Information Systems Agency (DISA), User Interface Specifications For The Defense Information Infrastructure (DII), Version 2.0 Preliminary Draft, December 31, 1995. (2.1.8)

**Example:**

2.1.1 Present map overlays in succession. Show changes in the tactical situation database.

2.1.2 Ideally, as one new point is plotted, the oldest point should be removed, thereby maintaining a constant number of displayed points.

2.1.3 Borders can add visual clutter to a display, increasing information processing time. Borders should only be used for functional purposes, such as to facilitate grouping.

2.1.9 Provide the capability to remove friendly symbology from a highly cluttered display.

2.1.10 For instance, all friendlies could be grouped under one summary friendly symbol in a zoomed display.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. (2.1.1 through 2.1.10)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 2.0 Display Formatting** **Category: 2.2 Density**

**Rationale:**

Density is the amount of display space used expressed as a percentage of the total usable display area. There is a point at which information overload on the display negatively affects crewmember performance. Research indicates a significant decrease in crewmember performance for display density greater than 50%. The more complex the display, the more time it takes to read and interpret the information presented. Very complex displays may also cause the crewmember to misinterpret information or fail to use it correctly.

**Guidelines:**

2.2.1 Screen packing density should not exceed 50%, and preferably should be less than 25%.

2.2.2 Display presentations should be perceived as "uncluttered."

2.2.3 Provide only information essential to making a decision or performing an action. Search times increase with the amount of irrelevant information on a display.

2.2.4 All information related to a particular task should be placed on the same display.

2.2.5 Interim information should be removed from the display once it is no longer needed.

2.2.6 Use the simplest, most natural, and intuitive display concepts commensurate with the information transfer needs of the crewmember.

2.2.7 When displaying tables with many rows, a blank line or some other distinctive feature should be inserted after every fifth row, space permitting, as an aid to horizontal scanning.

2.2.8 Minimize information density on displays used for critical task sequences. A minimum of one character space should be left blank vertically above and below critical information with a minimum of two character spaces left blank horizontally before and after.

2.2.9 When lists or tables extend beyond one display page, the crewmember should be informed when a list is or is not complete.

2.2.10 Where crewmember information requirements vary or cannot be accurately determined in advance of interface design, on-line options should be provided for information selection, display coverage, and suppression.

2.2.11 Develop a hierarchy of information needs and incorporate a compatible declutter capability.

2.2.12 Use enhancement coding to display more information while adhering to density guidelines. (Refer to Categories 4.1, 4.2, 4.3, 4.4.)

2.2.13 For a highly cluttered search field containing objects differing widely in size, color, and shape, crewmembers can locate specific objects considerably faster when they know in advance the object's color rather than its size or shape. (Refer to Categories 3.1, 3.5, 3.6.)

2.2.14 The value of color coding varies with information density. Search times increase with larger color coding sets at higher display densities. (Refer to Category 3.1.)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **2.0 Display Formatting** | **Category:** **2.2 Density**

**References:**

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985. (2.2.1, 2.2.2, 2.2.3, 2.2.4, 2.2.10)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (2.2.9)

Harrison, J., Janowitz, J., Castronuovo, M., Pilot-Vehicle Interface, Federal Aviation Administration, DOT/FAA/CT-92/21, 1993. (2.2.4, 2.2.5, 2.2.6, 2.2.8)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (2.2.7, 2.2.8, 2.2.11, 2.2.12)

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (2.2.13, 2.2.14)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (2.2.3)

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (2.2.14)

**Example:**

2.2.5 When entering the positional information of a waypoint, remove the entered information following acceptance of the waypoint into the navigation system.

2.2.7 Use spaces and lines to perceptually organize and balance the display presentation.

```
xxxxx   xxxxxx  yyyyyyyy        aaaaaaaa        wwwwwwww
xxxxx   xxxxxx  yyyyyyyy        aaaaaaaa        wwwwwwww
xxxxx   xxxxxx  yyyyyyyy        aaaaaaaa        wwwwwwww
xxxxx   xxxxxx  yyyyyyyy        aaaaaaaa        wwwwwwww
xxxxx   xxxxxx  yyyyyyyy        aaaaaaaa        wwwwwwww

aaaaaa  gggg    hhhhhh  ######  %%%%%%%         zzzzzzzz
aaaaaa  gggg    hhhhhh  ######  %%%%%%%         zzzzzzzz
```

2.2.9 "Page down to continue" or "End of Table" is an example of this principle.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Assessment techniques for ensuring display density are both quantitative and qualitative. A percentage of the display area can be calculated to provide an approximate value for display density, although a qualitative judgment may be appropriate. Ensure that information related to a specific task is displayed on a single display page. Ensure that information is removed from the display in an appropriate time and manner. Ensure that dense table rows are appropriately separated. (2.2.1 through 2.2.14)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 2.0 Display Formatting** **Category: 2.3 Windowing**

**Rationale:**

A window provides the visual means by which the crewmember can interact with the weapon system. A window displays the results of command or data input by keyboard, cursor, or other device. Adding windows to a display can increase the conceptual complexity of control actions as well as the difficulty of data assimilation. The information display windows must be designed so that the crewmembers can locate the desired information and obtain simple answers to questions needing complex processing.

**Guidelines:**

**General**

2.3.1 Windows should be perceptually distinct from the rest of the display.

2.3.2 Window overlays should be nondestructive and should not permanently erase overlaid information.

2.3.3 Default formats should represent the configuration of the information to be displayed.

2.3.4 Crewmember control of windows should operate consistently from one display to another for each type of window.

2.3.5 Window overlays may be provided to temporarily add information to a display, as a means of controlling or displaying divergent information, or to segregate and control separate operations.

**Design/Layout**

2.3.6 The display should be capable of presenting multiple windows simultaneously, in either a tiled or overlapped format, as requested by the crewmember.

2.3.7 Design the vertical layout so crewmembers are not required to scroll within a window to see an entire "page." Otherwise, the crewmember is forced to remember objects that are not always visible on the display.

2.3.8 Design the initial presentation size and shape of a window to be consistent with its contents (amount of information, number of menus, information fields, etc.).

2.3.9 Windows which are dedicated to keyboard command entry input should be located at the bottom of the display area.

2.3.10 Visually separate windows from each other and from their background by borders or similar demarcation.

2.3.11 Windows should be identified by a label consistently located at the top of the window's border. Where several windows can be displayed at one time, active windows should be indicated by labeling or other means, and an easy means of shifting among windows should be provided.

2.3.12 Make the design focus on the task rather than on the system. Make arrangement of items on the screen (in menus, lists, tables, etc.) reflect task requirements and not system characteristics.

2.3.13 Use system capabilities because they enhance crewmember task accomplishment, not simply because they can be used (e.g., color, highlighting techniques, graphics).

2.3.14 If screen capacity limits display of both graphic information and menus, provide temporary superposition of menu windows on displayed information.

2.3.15 When a coherent display is required to aid crewmember perception of relations among data sets, provide this information in an integrated display rather than partitioning them into separate windows.

2.3.16 Ensure that the central processor has the power, in terms of memory and speed, to effectively use a windows approach. Without proper hardware, slow system-response time will significantly degrade the speed of information presentation.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 2.0 **Display Formatting** **Category:** 2.3 **Windowing**

**References:**

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation Bedford, Massachusetts, USA, 1986. (2.3.14, 2.3.15)

Lynch, P. J., Graphics in the Interface, Yale Center for Advanced Instructional Media, Journal of Biocommunications, 1994. (2.3.7)

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (2.3.1, 2.3.2, 2.3.12, 2.3.13)

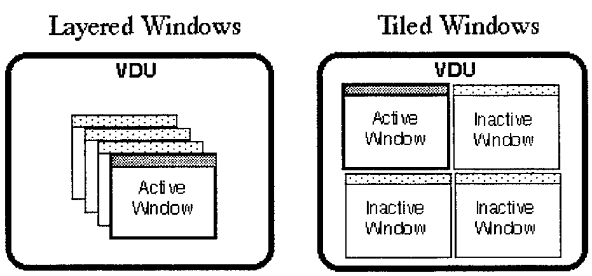
Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (2.3.16)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (2.3.3, 2.3.5, 2.3.6, 2.3.8, 2.3.9, 2.3.10, 2.3.11)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (2.3.4)

**Example:**

2.3.4 Active windows in both the tiled and layered window environments should be perceptually distinct from inactive window types.




2.3.5 Display help screens, menus, or other information by using overlays.

2.3.12 Task or function allocation fall into this category.

2.3.15 Display offensive/defensive stores (missiles/chaff/flares/decoys, etc.) management in an integrated display.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate windowing methods under typical cockpit environmental and operational conditions with a representative crewmember population. (2.3.1 through 2.3.16)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 2.0 Display Formatting** **Category: 2.3 Windowing**

**Guidelines (continued):**

**Design/Layout (continued)**

2.3.17 Avoid windowing when hardware has the following limitations:

a. Small screen size, resulting in frequent screen manipulation by crewmembers.

b. Slow processing speed, resulting in slow real-time applications operation.

c. Low screen resolution, resulting in less effective visual coding, especially for tactical map graphics symbols and icons.

2.3.18 When there is a predefined cursor HOME position, consistently define that position for all displays of a given type. The cursor HOME position should also be consistent in partitioned displays.

2.3.19 Ensure the default height for text windows and windows used for information scanning is at least four lines. Windows with more than four lines show little advantage over windows with four lines.

2.3.20 Position windows in such a way that menu bars, access to the command area, or caution and warning messages are not obscured.

**Data Entry/Information Retrieval/Feedback**

2.3.21 Keyboard input should affect only the crewmember designated active window.

2.3.22 If windows are capable of different modes (real-time information display, recap, command input/selection, etc.), the system should provide immediate and unambiguous feedback concerning active modes.

2.3.23 The system should be capable of alerting crewmembers to critical information that becomes available in an inactive or nondisplayed window.

2.3.24 Provide cues to identify the currently displayed page and the total number of pages of a multipage display.

2.3.25 Display available transaction options.

2.3.26 Make editable fields clearly distinguishable from noneditable fields.

2.3.27 Provide crewmembers means to log-off by a single action (e.g., menu option, command input).

2.3.28 When the primary display is formatted for graphic display or for process control, a separate display window should be reserved for information entry.

2.3.29 When crewmember information requirements cannot be determined in advance, provide a separate display window "notepad/scratchpad" on which a crewmember can preserve needed items.

2.3.30 Caution and warning windows should be frontmost on the display. The system should alert crewmembers to critical information that becomes available in an inactive or nondisplayed window.

2.3.31 Labels should remain on the display while the information scrolls beneath them (such as headings on a chart).

**Positioning/Control**

2.3.32 Windows characteristics should be predefined and displayed under crewmember control.

2.3.33 Windows command syntax, semantics, and operational control should be consistent throughout the system.

2.3.34 Provide protection against exiting an information file without the opportunity to save the contents.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 2.0 **Display Formatting** **Category:** 2.3 **Windowing**

**References:**

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (2.3.24, 2.3.25, 2.3.26, 2.3.27, 2.3.34)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (2.3.21, 2.3.22, 2.3.23, 2.3.31, 2.3.32, 2.3.33)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation Bedford, Massachusetts, USA, 1986. (2.3.28, 2.3.29)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (2.3.18, 2.3.19, 2.3.20, 2.3.30)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (2.3.17)

**Example:**

2.3.17 Some cockpit displays may not support a windows approach to information display because of size, function, or resolution.

2.3.18 HOME might be in the upper left corner of a text display, or the first field in a form-filling display, or the center of a graphic (map) display.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate windowing methods under typical cockpit environmental and operational conditions with a representative crewmember population. (2.3.17 through 2.3.34)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 2.0 **Display Formatting** **Category:** 2.3 **Windowing**

**Guidelines (continued):**

**Positioning/Control (continued)**

2.3.35 Permit crewmembers to exit a file without saving file changes.

2.3.36 Permit crewmembers to change horizontal and vertical window dimensions.

2.3.37 Permit crewmembers to move windows to different display locations.

2.3.38 When hierarchical levels are used to control a process or sequence, minimize levels to three or less.

2.3.39 Design control functions so crewmembers can open or close a window with a single action.

2.3.40 Crewmembers should be able to select separate data windows sharing a single display screen.

2.3.41 When control actions such as command entry are taken by crewmembers working within a window, they should be consistent from one window to another.

2.3.42 Permit crewmembers to place a window in the inactive state by performing a set of simple actions in that window or related to that window. If several windows are displayed at once, the window(s) in which action can be taken should be indicated.

2.3.43 Permit crewmembers to move windows to different display areas.

2.3.44 Develop a display freeze capability for automatically updated windows.

2.3.45 Ensure windows that are not displayed are capable of receiving information.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 2.0 Display Formatting** **Category: 2.3 Windowing**

**References:**

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (2.3.35, 2.3.36, 2.3.37, 2.3.38)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (2.3.39, 2.3.40, 2.3.41, 2.3.43, 2.3.44, 2.3.45)

**Example:**

2.3.39 Control of predefined windows may simply involve "opening" and "closing" them, by selecting displayed option labels or function keys. Control of crewmember-defined windows may require crewmember specification of window contents, window size, and positioning on the display. Such window control must be learned by a crewmember, and consistent design of control logic will aid that learning.

2.3.40 A prominent cursor might be displayed in the currently active window, or the displayed border of an active window would indicate which window is currently "active."

2.3.41 Cursor positioning controls should operate consistently within all windows. If controls in one window operate differently than in another, crewmember confusion will result.

2.3.42 A window might be activated by moving the pointing cursor to the window and performing any action, including pressing a key or a button on a cursor control device, issuing a command to open a specific window, selecting a window title from a list on a menu, or selecting an icon representing the window.

2.3.44 When a window displays automatically updated information, the crewmember should have control over the rate at which automatically updated screens are scrolled.

2.3.45 A communications page should continue to receive updated frequency information even if it is not displayed.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate windowing methods under typical cockpit environmental and operational conditions with a representative crewmember population. (2.3.35 through 2.3.45)

THIS PAGE INTENTIONALLY LEFT BLANK

**Functional Area: 3.0 Information Coding**

3.1 Color
3.2 Location
3.3 Orientation
3.4 Pictorial (Mimics, Diagrams, Icons, Symbols)
3.5 Shape/Symbol
3.6 Size/Symbol

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** | **Category:** **3.1 Color**

**Rationale:**

Color coding of displays can sometimes improve visual search and identification performance over monochrome formats. The impact of color coding is highly situation specific and depends on factors such as operator task, display format and density, and work environment. For highly dense displays with a visual search requirement, color coding provides performance enhancement not available with other coding methods. However, irrelevant use of color, or using seven or more colors in computer generated displays, can cause performance decrements. There is also some evidence that color coding may improve visual search and identification performance when task loading is high. Operator preference strongly favors color displays.

Color is a good auxiliary code, where a multicolor display capability is available. A color code can be overlaid directly on alphanumerics and other symbols without significantly obscuring them, and color coding permits rapid scanning and perception of patterns and relationships among dispersed information items. Color influences the crewmember to pay particular attention to a command, a portion of a screen, an error message, or any part of the interface requiring notice. How the color of a foreground object is perceived is directly related to its background color. Color should add substance to the interface, not dominate it.

**Guidelines:**

3.1.1 Use color coding, where appropriate, to differentiate between classes of information in complex, dense, and critical displays. Employ color coding conservatively, using relatively few colors and only to designate critical categories of displayed information. Limit the number of colors used -- normally four for a single screen and seven for the entire sequence of screens.

3.1.2 The following reserved color meanings should be used:

RED should be used to indicate conditions such as "no-go," "error," "failure," "malfunction," "danger," etc.

FLASHING RED should be used only to denote emergency conditions requiring immediate operator action, or to avert personnel injury, equipment damage, or both.

YELLOW should be used to indicate marginal conditions or to alert situations where caution, recheck, or unexpected delay is necessary.

GREEN should be used to indicate that monitored equipment/processes are within tolerance or a condition is satisfactory and that it is all right to proceed with an operation or transaction.

WHITE should be used to indicate system conditions that do not have operability or safety implications, but indicate alternative functions.

BLUE may be used as an advisory color, preferential use of blue should be avoided.

3.1.3 Color may be used to identify information categories when it does not conflict with other color coding conventions and does not conflict with other color associations (as in 3.1.2). Use of color as a formatting code should be secondary to other methods.

3.1.4 Color coding should be redundant to some other means of coding such as symbology. Coding only by color should be avoided. Displayed information should provide necessary information even when viewed on a monochromatic display terminal or hard-copy printout.

3.1.5 Consider the ambient lighting under which the display will be viewed when deciding the desired saturation of any given display color. Colors that appear highly saturated in a darkened environment will appear less saturated when viewed under high ambient illumination.

3.1.6 Colors should be easily discriminable and color coding should be used conservatively. Each color should represent only one category of displayed information. Color will prove the dominant coding dimension on a display.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.1 Color**

**References:**

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (3.1.1, 3.1.2, 3.1.3, 3.1.4, 3.1.5, 3.1.6)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (3.1.4)

**Example:**

3.1.1 Different colors could be used to provide amplifying information regarding the composition of forces. (Red could be used to denote a hostile airborne contact.)

3.1.3 A hostile airborne contact symbol depicted in red falls into this category.

3.1.4 Color alone should not be used to denote a Friendly, Hostile, or Unknown target.

3.1.6 If several different categories of information are displayed in red, they will have an unwanted visual coherence which may hinder proper assimilation of information by the crewmember.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Evaluate color coding methods under typical cockpit environmental and operational conditions with a typical crewmember population. Colors selected for coding should be tested with crewmembers to ensure that they are easily discriminable. Testing should be conducted under realistic conditions, since such factors as display type and ambient lighting will affect color perception. Ensure compatibility of colors with night vision devices. (3.1.1 through 3.1.6)

## *SA IMPROVEMENT GUIDELINE*

| **Functional Area:** <u>3.0</u> **Information Coding** | **Category:** <u>3.1</u> **Color** |
|---|---|

**Guidelines (continued):**

3.1.7 Brighter or more saturated colors should be used when it is necessary to draw crewmember attention to critical information.

3.1.8 Color line coding may be used to advantage for guiding the visual scanning required to trace paths.

3.1.9 When different areas of a map must be defined, or when the geographic distribution of a particular variable must be indicated, consider the use of texture patterns, color, or shades for that purpose.

3.1.10 If colors will be used for displaying text, care should be taken to ensure that colored letters are legible as well as discriminable.

3.1.11 For a color code, each definition should be displayed in its appropriate color, as I RED = hostile I displayed in red.

3.1.12 Consider displaying gradual color shade changes to show the relative values of a single variable. A gradual change in color can be achieved by varying saturation, starting with a saturated hue and gradually adding white. Gradual color changes should not be used when absolute values are important or to code information into discrete categories.

3.1.13 Consider using a unique color to display discrete categories of dispersed information. Ensure that colors are easily discriminable.

3.1.14 Highlight critical information by bolding/brightening, color coding, or some auxiliary annotation, to set it apart from other information.

3.1.15 Design consideration: The harder it is for a crewmember to identify a displayed color, the less useful the color code. If many colors are used, colors will be closer in hue and harder to discriminate. Color coding, when applied to symbols that subtend small visual angles, which makes color perception difficult, will require a special need to limit the number of colors used.

3.1.16 Do not use colors arbitrarily. Casual, arbitrary use of colors may cause displays to appear "busy" or cluttered. Casual use of color will also reduce the likelihood that significant color coding on particular displays will be interpreted appropriately and quickly by a crewmember.

3.1.17 Do not use color coding in an attempt to compensate for poor display format. Redesign the display instead.

3.1.18 Use saturated blue only for background features in a display, and not for critical information. Saturated blue might be used for shading background areas in graphic displays, where its lower apparent brightness could be of benefit, or saturated blue might be used to display a background grid or familiar scale on a graphic display. The human eye is not equally sensitive to all colors, nor are its optics color-corrected.

3.1.19 Design consideration: Color, as studied in binocular vision, has been shown to be a cue to depth perception, but the cue can lead to ambiguous results. Subjects have reported that red appeared to be "nearer" than green or blue, and that green was "nearer" than blue. This effect is often referred to as "chromostereopsis". These results need to be considered within the context of constructing spatial displays. If designers are trying to isolate and examine a specific depth cue effect, they must be cautious to not introduce unwanted effects due to these color phenomena. One suggestion may be to use stimuli with less unsaturated colors, and to control for the effects across variables of interest.

3.1.20 Blue symbols appear dimmer than others, and are more difficult to focus. If blue must be used for displayed information, use a desaturated blue or cyan to make the information more legible. Because the eye is relatively insensitive to blue, blue lines or dots will be difficult to resolve. Avoid using saturated blue for small lines or dots when the background is dark.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.1 Color**

**References:**

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (3.1.7, 3.1.10)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (3.1.8, 3.1.9, 3.1.10, 3.1.11, 3.1.12, 3.1.13, 3.1.14, 3.1.15, 3.1.16, 3.1.17, 3.1.18, 3.1.20)

Crvarich, G., An Exploration of Techniques to Improve Relative Distance Judgments within an Exocentric Display, 1995. (3.1.19)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (3.1.19, 3.1.20)

**Example:**

3.1.8 Colored lines could be used to advantage in depicting a fuel, hydraulic, or electrical system schematic display.

3.1.12 In displaying ocean depth, a saturated blue might be used to show the deepest point, with gradually desaturated blues to show decreasing depth. The change can be in intensity, starting with an intense hue and gradually adding black, or the change might be in hue, moving gradually from red through orange, yellow, green, etc.

3.1.19 Examples include such color pairs as red and blue, yellow and purple, or magenta and green. The effect (a 3-D effect called chromostereopsis) is most significant with red and blue.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Evaluate color coding methods under typical cockpit environmental and operational conditions with a typical crewmember population. Colors selected for coding should be tested with crewmembers to ensure that they are easily discriminable. Testing should be conducted under realistic conditions, since such factors as display type and ambient lighting will affect color perception. If colors will be used for displaying text, care should be taken to ensure that colored letters are legible as well as discriminable. Ensure compatibility of colors with night vision devices. (3.1.7 through 3.1.20)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 3.0 **Information Coding** **Category:** 3.1 **Color**

**Guidelines (continued):**

3.1.21 Avoid the following color pairings on the same screen:

| | |
|---|---|
| red and blue | red and green |
| blue and green | yellow on white |
| yellow on purple | green on white |
| yellow on green | blue on black |
| magenta on green | red on black |
| magenta on black | |

3.1.22 Ensure that color-coded symbols subtend a minimum of 20 min of visual arc. The designer must determine the maximum viewing distance from the display, then calculate the minimum size of the object, using the formula:

$$\text{Visual Angle (Min.)} = (57.3)\,(60)L\,/\,D$$

where L = size of the object and D = distance from the eye to the object.

3.1.23 Design consideration: Color can be a very effective discriminator, for example, by decluttering a display and improving task performance. Color can also introduce the very clutter and performance degradation it attempts to reduce. For these reasons, color in a display must be used very carefully.

3.1.24 Use color sparingly as an information discriminator. Color rapidly loses meaning and, when overused, may impede rather than enhance human performance.

3.1.25 Use colors consistently within a display and across a set of displays for an application.

3.1.26 Ensure color meaning is consistent with user expectation.

3.1.27 Ensure high contrast between the text or graphical object and its background to enhance screen readability. Generally, the color foreground should differ from its background by a minimum of 100 E (CIE Yu'v') distances.

3.1.28 The level of ambient illumination directly affects the perceived brightness and hue of a color. Consider the following when designing a color display:

- Red is best used under high ambient lighting conditions.
- Yellow provides good general visibility over a broad range of luminances.
- Green provides good general visibility over a broad range of intermediate luminances.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.1 Color**

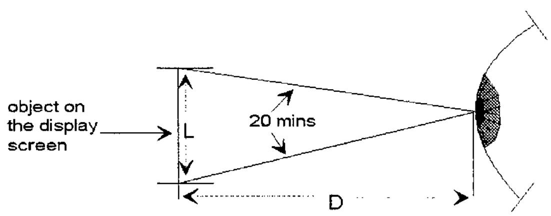
**References:**

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (3.1.21)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (3.1.22, 3.1.23, 3.1.24, 3.1.25, 3.1.26, 3.1.27, 3.1.28)

**Example:**

3.1.22




**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Evaluate color coding methods under typical cockpit environmental and operational conditions with a typical crewmember population. Colors selected for coding should be tested with users to ensure that they are easily discriminable. Testing should be conducted under realistic conditions, since such factors as display type and ambient lighting will affect color perception. If colors will be used for displaying text, care should be taken to ensure that colored letters are legible as well as discriminable. Ensure compatibility of colors with night vision imaging systems (NVIS). (3.1.21 through 3.1.28)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 3.0 Information Coding** **Category: 3.2 Location**

**Rationale:**

Whenever a crewmember is faced with a large number of items on a display, including display controls, location becomes a prime factor in display design. Search times to locate objects on a display or to locate controls are decreased by consistent placement of components. Location of recurring functional groups and individual items should be similar from panel to panel and display to display. Mirror image arrangements should not be used.

**Guidelines:**

3.2.1 Adopt a consistent organization for the location of various display features from one display to another:

- Commands should be entered and displayed in a standard location on the display.
- System messages should appear in standard locations. Messages may be provided in window overlays.
- Information displayed to provide context for crewmember entries should be distinctive in location and format and consistently displayed from one transaction to the next.
- Menus should be displayed in consistent screen locations for all modes, transactions, and sequences.

3.2.2 Control and display location and arrangement should be designed to aid in determining which controls are used with which displays, which equipment component each control affects, and which equipment component each display describes.

3.2.3 A visual display that must be monitored concurrently with manipulation of related controls should be located so that the crewmember is not required to observe the display from an extreme visual angle and thus introduce the possibility of parallax error.

3.2.4 When separate displays are affected by a combined control (e.g., concentrically ganged knobs), the displays should be arranged from left to right with the combined control underneath the center of the displays, but not so that displays are obscured when controls are manipulated.

3.2.5 When related controls and displays must be located on separate panels and both panels are mounted at approximately the same angle relative to the crewmember, the control positions on one panel should correspond to the associated display positions on the other panel. The two panels should not be mounted facing each other.

3.2.6 When a group of equipment components has the same function, the related control and display positions should be oriented to correspond to those of the controlled and monitored components.

3.2.7 Emergency displays and controls should be located where they can be seen and reached with minimum delay.

3.2.8 Displays should be located and designed so that they may be read to the degree of accuracy required by crewmembers in the normal operating or servicing positions without requiring them to assume an uncomfortable, awkward, or unsafe position.

3.2.9 Display faces should be perpendicular to crewmember normal line of sight when feasible and should not be less than $\pi/4$ rad (45 deg) from the normal line of sight. Parallax should be minimized.

3.2.10 Displays should be constructed, arranged, and mounted to prevent reduction of information transfer due to reflection of ambient illumination from display covers. Reflection of instruments and consoles in windscreens and other enclosures should be avoided. If necessary, techniques (such as shields and filters) should be used to ensure that system performance will not be degraded.

3.2.11 Red alphanumeric LED's/segmented displays should not be grouped with or located adjacent to red warning lights.

3.2.12 Pattern and location coding should be used to reduce crewmember search time by restricting the search area to prescribed segments.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.2 Location**

**References:**

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (3.2.1)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.2.1)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (3.2.1 through 3.2.12)

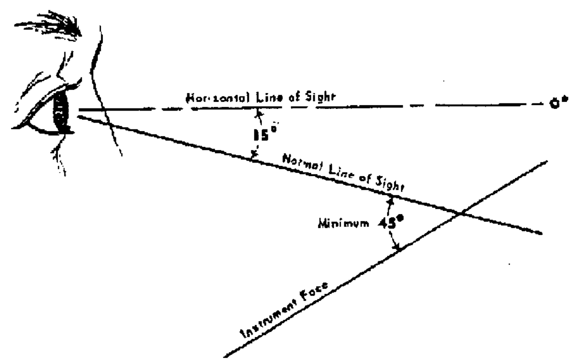
**Example:**

3.2.1 One location might be used consistently for a display title; another area might be reserved for information output; and other areas dedicated to displaying control options, instructions, error messages, and crewmember command entry.

3.2.6 The position of aircraft engine controls should be oriented as if the crewmember faces the normal direction of vehicle movement.

3.2.7 Warning lights should be located within a 30-deg cone about the operator's normal line of sight; an emergency control should be located close to its related warning display or the nearest available hand in its nominal operating position.

3.2.9




**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate location coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.2.1 through 3.2.12)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.2 Location**

**Guidelines (continued):**

3.2.13 Location of recurring information should be similar among all tabular information displayed and should be common throughout the system.

3.2.14 Tabular information should be displayed in rows and columns. If information in rows has order, the order should be increasing from left to right. If information in columns has order, the order should be increasing from top to bottom of the display.

3.2.15 Where lists extend over more than one display page, the last line of one page should be the first line on the succeeding page.

3.2.16 Group function keys in distinctive locations on the keyboard to facilitate their learning and use; place frequently used function keys in the most convenient locations.

3.2.17 When a transilluminated indicator is associated with a control, the indicator light should be located so that it is associated with the control without error and should be visible to the operator during control operation.

3.2.18 Crewmembers viewing a portion of a larger display should be provided with an indication of the location of the visible position of a display (frame) in the overall display.

3.2.19 A page location reference within the display sequence should be provided for multipage displays.

3.2.20 On the initial appearance of a data entry display, the cursor should appear automatically at some consistent and useful location.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.2 Location**

**References:**

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (3.2.13, 3.2.14, 3.2.15, 3.2.16, 3.2.19)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.2.17, 3.2.18, 3.2.19, 3.2.20)

**Example:**

3.2.18 In a corner of the frame, show a rectangle representing the overall display, in which a smaller rectangle is placed to indicate the position and extent of the currently visible portion of that display.

3.2.19 Typically, the phrase "page x of y" is used for this purpose. A recommended format is to identify pages by a note immediately to the right of the display title. Leading zeros should not be used in displaying page numbers.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate location coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.2.13 through 3.2.20)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.3 Orientation**

**Rationale:**

The spatial orientation of a pattern affects its perceived shape. Consequently, the identity of two patterns which differ only in orientation may not be readily evident. In fact, an observer may fail to recognize a pattern seen before if it is presented in an unfamiliar orientation. Exceptions to spatial orientation occur when an observer can consistently assign top, bottom, and sides to a figure despite changes in orientation. The following orientation factors affect aircraft displays (Boff and Lincoln, 1988):

- A very familiar figure is recognized even when seen in an unfamiliar orientation.
- A figure with a prominent intrinsic axis and some degree of symmetry about that axis does not look very different in other orientations.
- Mirror image reversal does not greatly affect perceived shape.
- Knowledge about a figure's orientation (i.e., where the top is located) opposes changes in perceived shape.
- For fairly complex forms, the ability to assign a consistent top or bottom may be insufficient for proper shape recognition.
- A figure's shape usually does not appear different if its orientation is changed only with respect to retinal coordinates (as, for example, when the observer is tilted and the figure remains upright).
- Displays requiring depth judgments must account for different stereoscopic sensitivities for elements at nonvertical orientations, especially those at inclination angles >45 deg.
- Bar patterns are less visible when oriented obliquely than when oriented vertically or horizontally. This decrement becomes more pronounced as barsize decreases.
- Elongated targets have lower thresholds at horizontal and vertical orientations than at oblique orientations, a phenomenon know as the oblique effect.
- Detection of the orientation of target symbols moving down a video display is degraded as symbol size decreases and velocity increases. The detection of symbol orientation varies greatly depending on the direction of movement.
- Tilting the head or deviating the eyes for a short period causes error in judgments of visual spatial location, with apparent vertical deviation in the direction opposite the head tilt.
- The apparent orientation, or tilt, of a given line (test line) is affected by a neighboring line (induction line) with a different tilt. The tilt illusion refers to the perceived tilt of the test line in a direction opposite that of the induction line.

**Guidelines:**

3.3.1 In a related series of bar charts, a consistent orientation of the bars (vertical or horizontal) should be adopted. If bar length is used to represent time duration, then it might be more appropriate to orient the bars horizontally, in accord with the general convention of plotting time on the horizontal axis of a graph. Vertical bars can be used to display frequency counts or a large variety of other measured attributes.

3.3.2 The crewmember should be able to select different orientations and reference points. The system should provide the crewmember with a listing of the common orientations and reference points. The selected orientation should be clearly indicated, e.g., with a label.

3.3.3 The pointer on fixed scales should extend from the right of vertical scales and from the bottom of horizontal scales.

3.3.4 The annotation of graphic displays, including labels for the axes of graphs, should be displayed in a normal orientation for reading text.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 3.0 **Information Coding** — **Category:** 3.3 **Orientation**

**Reference:**

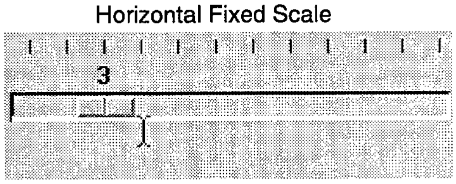
U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.3.1, 3.3.2, 3.3.3, 3.3.4)

**Example:**

3.3.2 When displaying a digital map, the crewmember should be able to orient the map either North Up or Track Up.

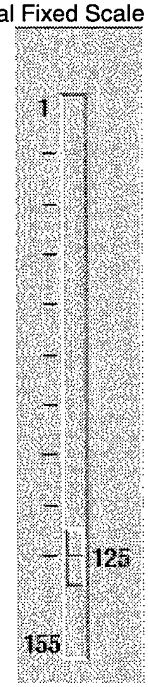
3.3.3 Fixed horizontal and vertical scales:

Horizontal Fixed Scale




The pointer on a fixed horizontal scale should extend from the bottom.

Vertical Fixed Scale




The pointer on a fixed vertical scale should extend from the right.

3.3.4 Crewmembers should be presented with horizontally displayed labels, even for the vertical axis of a graph. A conventional text orientation of labels will permit faster, more accurate reading.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Apply these guidelines to tactical displays and evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. (3.3.1 through 3.3.4)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.3 Orientation**

**Guidelines (continued):**

3.3.5 Icons, symbols, and numbers should always be oriented "upright."

3.3.6 The orientation of scale markings should be consistent to facilitate accurate reading (e.g., orientation of numerals, scale end-points on dials).

3.3.7 Display faces should be perpendicular to crewmember normal line of sight whenever feasible and should not be less than 45 deg from the normal line of sight. Parallax should be minimized. (Refer to Category 3.2.)

3.3.8 The increase of numerical progression on fixed scales should read clockwise, from left to right, or from the bottom up, depending on display design and orientation. Numerals on fixed scales should be upright when in the reading position.

3.3.9 On fixed-pointer, moving scale indicators, numbers should progress clockwise around the faces of circular dials (counter-clockwise dial movement for numerical increase). On vertical or horizontal straight moving scales, numbers should increase from bottom to top or from left to right. Numerals on moving scales should be upright when in the reading position.

3.3.10 Where pointer movement is more than 360 deg, the zero point should be located at the 12 o'clock position. Where positive and negative values are displayed around a zero or null position, the zero or null point should be located at the 12 o'clock position.

3.3.11 Process control and input device locks should be oriented so that the OFF or SAFE state is in effect when the key/switch is in the vertical position.

3.3.12 Rocker switches should ordinarily be oriented vertically. Activation of the upper part should control the ON or INCREASE function. Horizontal orientation should be used only when required by the location of the controlled function or equipment.

3.3.13 Horizontal rows of displays should be used rather than vertical columns.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.3 Orientation**

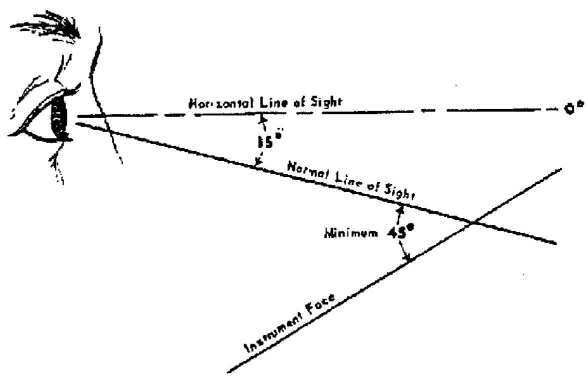
**References:**

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.3.5, 3.3.6, 3.3.10, 3.3.11, 3.3.12, 3.3.13)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (3.3.7, 3.3.8, 3.3.9)

**Example:**

3.3.7




3.3.10 Barometric altimeters normally have the zero point at the 12 o'clock position.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Apply these guidelines to tactical displays and evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. (3.3.5 through 3.3.13)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.4 Pictorial (Mimics, Diagrams, Icons, Symbols)**

**Rationale:**

In order to think, we must speculate in images - Aristotle 350 B.C.

Where there is a choice whether to use symbolic or verbal information coding, symbolic coding is preferable if the symbol reliably depicted visually what it is intended to represent. One argument for this (supported by research) is that symbols do not require the recoding that words or short statements do.

**Guidelines:**

**Mimics/Diagrams**

3.4.1 Mimics and diagrams should contain the minimum amount of detail required to yield a meaningful pictorial representation.

3.4.2 All flow path line origin points should be labeled or begin at labeled components. All flow path line destination or terminal points should be labeled or end at labeled components.

3.4.3 Flow directions should be clearly indicated by distinctive arrowheads.

3.4.4 Flow paths should be coded (e.g., by color, width) to indicate important information.

3.4.5 Flow paths should not overlap. Cross-overs should be clearly indicated so that they do not appear as connections.

3.4.6 Where symbols are used to represent equipment components and process flow or signal paths, numerical information should be presented reflecting inputs and outputs associated with equipment. Where sequential relations between display elements require highlighting, animation may be used.

3.4.7 When crewmembers must analyze pictorial or mimic information in detail, computer aids should be provided.

3.4.8 Zones indicating operating ranges should be color coded by edge lines or wedges for circular scales.

3.4.9 When reading positive or negative values of graphical displays, the zero or null position should be at 12 o'clock or 9 o'clock.

3.4.10 The pointer on fixed scales should extend from the right of vertical scales and from the bottom of horizontal scales.

3.4.11 The pointer on fixed scales should extend to but not obscure the shortest graduation marks.

3.4.12 Tic marks should be separated by at least 0.07 in. (1.75 mm) for a viewing distance of 28 in. (71 cm) under low illumination (less than 1.0 ft-L).

3.4.13 Scales should not be cluttered with more marks than necessary for precision.

**Icons/Symbols**

3.4.14 The primary use of icons in graphic displays should be to represent actual objects or actions, and should be designed to look like the objects, processes, or operations they represent by use of literal, functional, or operational representations.

3.4.15 Icons should be simple closed figures when possible. When icons are too visually complex, they are not quickly recognized, which eliminates the primary advantage of using icons, i.e., quick recognition. Simple, closed figures are processed more efficiently than are open figures. Make the icon large enough to be seen, recognized, and selected easily, generally 5 mm square and separated by at least 3 mm.

3.4.16 Abstract symbols should conform to crewmember conventions or to common electrical, mechanical, or aircraft symbol conventions when crewmember conventions do not exist.

3.4.17 Each icon and symbol should represent a single object or action, and should be easily discernible from all other icons and symbols.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 3.0 Information Coding** **Category: 3.4 Pictorial (Mimics, Diagrams, Icons, Symbols)**

**References:**

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.4.1, through 3.4.17)

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (3.4.15, 3.4.17)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (3.4.6, 3.4.14)

**Example:**

3.4.4 Color can be used to differentiate process flow paths: red may be used to code hydraulic lines (hydraulic fluid is red), yellow may be used for fuel system component lines (jet fuel yellowish), etc.

3.4.7 Allow a crewmember to request auxiliary displays of specified mimics or pictorials.

3.4.8 Zones can be used to indicate hydraulic pressure ranges, off-normal RPM levels, etc.

3.4.9 The Vertical Speed Indicator (VSI) and the barometric altimeter are examples.

3.4.14 Some pictorial symbols have conventional meanings within a crewmember population, which must be followed to ensure their correct interpretation (literal, a figure of a bomb; functional, a figure of a map for navigation functions; operational, a figure of a hand on a switch).

3.4.17 The distinguishing feature between icons should be external geometric configuration of the icon.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Conduct an initial assessment of pictorial coding methods using the evaluation assessments in 3.4.25. Evaluate pictorial coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.4.1 through 3.4.17)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 3.0 **Information Coding** **Category:** 3.4 **Pictorial (Mimics, Diagrams, Icons, Symbols)**

**Guidelines (continued):**

**Icons/Symbols (continued)**

3.4.18 Special symbols to signal critical conditions should be used exclusively for that purpose.

3.4.19 Icons and symbols should always be displayed upright and should also be highlighted.

3.4.20 Icons and symbols should be large enough for the crewmember to perceive the representation and discriminate it from other icons and symbols.

3.4.21 Icons should be accompanied by a text label which corresponds to the object or action. To the extent that it does not clutter or cause distortion of the icon, the label should be incorporated into the icon itself. Do not let the label obscure the icon. When icons are designed such that the label is inside the icon, the number of perceptual objects is reduced, resulting in enhanced processing of the label and the icon. The text label may be omitted for icons having unambiguous meanings to crewmembers.

3.4.22 Use the same icons for the same objects/actions across applications.

3.4.23 Do not use abstract or humorous designs for icons.

3.4.24 Simple texture codes should be used rather than elaborate patterns.

3.4.25 The following are some issues to use for evaluating symbols:

- Is symbol/message association easy? Representational and abstract symbols have visual resemblance; arbitrary or invented symbols must be learned (e.g., math symbols). Arbitrary symbols should be as unique or compact as possible because they require training.
- In a variety of cultures and situations, is the symbol equally appropriate? Icons created for one cultural group may generate incongruent or even opposite meaning for another group. Such differences may generate conflicts in communications.
- Will the symbol be appropriate in the future? Will the metaphor soon be obsolete?
- Is the symbol pleasing and noncontroversial?
- Is the symbol in accordance with existing international standard symbols (i.e., do not create new symbols if one already exists)?
- Can the symbol or its elements be applied systematically for a variety of interrelated concepts (i.e., can the elements form a rich symbolic language, combining them to form more complex symbols)?
- Is the symbol easy to reproduce in a variety of environment and situations? Can it be transferred to different systems and enlarged or reduced without losing crispness or detail?
- Is the symbol distinguishable from other symbols?
- Can the symbol be perceived from different distances, angles, conditions?
- Do icons have intrinsic meaning to the crewmember? The crewmember will associate a meaning with an icon, and the stronger the associated meaning, the more easily the icon will be recognized and remembered.
- Do icons provide a visual representation that matches user expectations and allows association between the icon and the function being controlled?

3.4.26 Definitions should be available for all symbols, icons, and coding techniques. A legend on the display may be provided for display conventions.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 3.0 **Information Coding** **Category:** 3.4 **Pictorial (Mimics, Diagrams, Icons, Symbols)**

**References:**

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.4.19, 3.4.20, 3.4.21, 3.4.26)

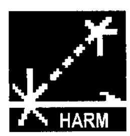
Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (3.4.21, 3.4.22, 3.4.23)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (3.4.24)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (3.4.25)

**Example:**

3.4.21 Icons should be accompanied by a text label which corresponds to the object or action.




**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Conduct an initial assessment of pictorial coding methods using the evaluation assessments in 3.4.25. Evaluate pictorial coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.4.18 through 3.4.26)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.5 Shape/Symbol**

**Rationale:**

A symbol is an object that conveys information. Graphic symbols may be one of three types: (1) representational - accurate simplified pictures of objects; (2) abstract - graphic symbols retaining only a faint resemblance to the original concept; and (3) arbitrary - symbols that have been invented and need to be learned. In actual practice, many of these graphical codes may not be solely confined to any one category. In general, symbolic/pictographic codes are more quickly detected and comprehended than word messages.

**Guidelines:**

3.5.1 Symbol coding should be used to enhance information transfer.

3.5.2 Symbols should be analogs of the event or system elements they represent, be in general use and well-known to the crewmembers, and be based on established standards or conventional meanings. Existing crewmember standards must be taken into account.

3.5.3 Symbol heights should not differ more than three sizes.

3.5.4 Special symbols, such as asterisks, arrows, etc., may be used to draw attention to selected items in alphanumeric displays. Use of special symbols should be consistent and their meanings unique.

3.5.5 Symbols should subtend a minimum of 20 min of arc.

3.5.6 Shape codes using more than 15 different shapes should be avoided. Component shapes may be used in combination.

3.5.7 Shapes used in coding for information groups should be clearly discriminable and vary widely.

3.5.8 Shape coding for controls is for identification of control knobs or handles by "feel;" however, shapes should be identifiable both visually and tactilely. When shape coding is used:

- The coded feature should not interfere with ease of control manipulation.
- Shapes should be identifiable by the hand regardless of the position and orientation of the control knob or handle.
- Shapes should be tactilely identifiable when gloves are worn.
- A sufficient number of identifiable shapes should be provided to cover the expected number of controls that require tactile identification.
- Shape coded knobs and handles should be positively and nonreversibly attached to their shafts to preclude incorrect attachment when replacement is required.
- Shapes should be associated with or resemble control function, but not alternate functions.

3.5.9 When using combinations of symbols, the following apply:

- Outlined diamonds are poor in discrimination and are often confused with other symbols.
- Outlined squares and circles are satisfactory in discrimination with other combinations.
- Outlined triangles are more discriminative than outlined diamonds but poorer than outlined squares and circles.
- Square and circle combinations have best search time ranking when compared with triangle or diamond combinations.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.5 Shape/Symbol**

**References:**

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (3.5.1 through 3.5.6)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.5.2, 3.5.7)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (3.5.4, 3.5.6)

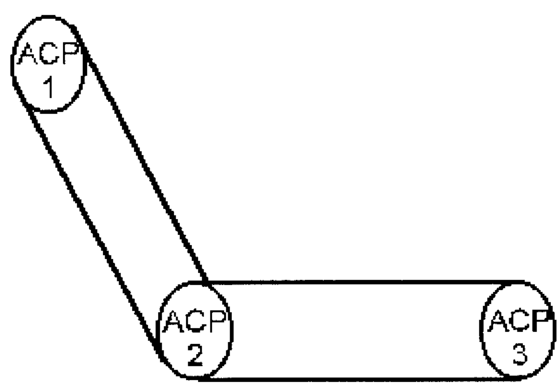
U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (3.5.8)

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985. (3.5.5, 3.5.9)

**Example:**

3.5.2 Coding with geometric shapes should be used to help crewmembers discriminate different categories of information on graphic displays. Although shape codes can often be mnemonic in form, their interpretation will generally rely on learned association as well as immediate perception.

3.5.6 A circle bounded by lines to depict an air corridor falls into this category.




**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate shape/symbol coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.5.1 through 3.5.9)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.5 Shape/Symbol**

**Guidelines (continued):**

3.5.10 When a new symbol is created, it should represent a basic, concrete concept because concrete symbols require less explanation than abstract ones. Compare each new symbol with existing symbols to ensure no conflicts exist.

3.5.11 Design the symbol as a structure of component parts, each providing clarifying information about the others. The totality of these components comprises the symbol:

- A frame should surround the basic symbol, and is used to facilitate rapid identification.
- Modifiers and text such as directional arrows (velocity leaders), alpha/numeric text, and unit symbols may be added to further define the symbol.
- Fields are combinations of letters, numbers, and/or abbreviations grouped in and around the basic symbol to provide additional information. This information may be another symbol (such as a size indicator), words, or numbers.
- The symbol's graphic component (or icon) is the innermost part of the symbol and is representative of an object of interest. The icon can also be called the basic symbol.
- The symbol's attributes are distinctive features or characteristics such as line, shape, color, texture (fill), edge, mass, and value.

3.5.12 Provide for the display of all available information regarding a specified symbol. However, system limitations, operational requirements, or clutter reduction may require the display of reduced amounts of information.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 3.0 **Information Coding** **Category:** 3.5 **Shape/Symbol**

**References:**

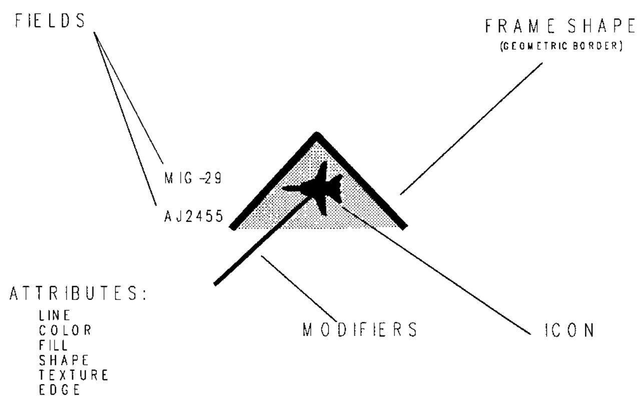
Defense Information Systems Agency (DISA), User Interface Specifications For The Defense Information Infrastructure (DII), Version 2.0 Preliminary Draft, December 31, 1995. (3.5.10)

U.S. Department of Defense, Common Warfighting Symbology, Version 1, MIL-STD-2525, 30 September 1994. (3.5.10, 3.5.11, 3.5.12)

**Example:**

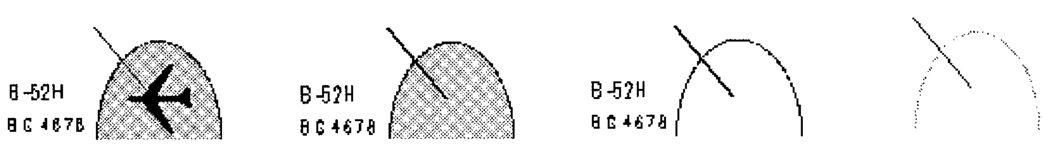
3.5.10 The symbol indicated below is an example of this guideline because it intuitively represents an aircraft carrier.

3.5.11 The components of the symbol are the frame (geometric border), attributes (e.g., color, shape), icon, fields, and modifiers.




Basic frame shapes (geometric borders) could identify the internal symbol or icon as either hostile, friendly, unknown, or neutral.

3.5.12 This is an example of progressively reducing symbology clutter.




**Method of Assessment:**

Incorporate testing procedures as integral parts of the symbol development process, and not solely as a post-design evaluation. Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate shape/symbol coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.5.10)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.6 Size/Symbol**

**Rationale:**

Character size is an important variable affecting performance error rates. Height and width of the character and the size of the pixel matrix have important effects on human performance. Exercise special care when determining the character size to use on a flat-panel display.

**Guidelines:**

3.6.1 Do not exceed three sizes for size coding; a larger symbol should be at least 1.5 times the height of the next smaller symbol. Human discrimination of more than three levels of size coding is easy. Recognition of more than three sizes, without benefit of comparisons, is difficult.

3.6.2 The height of characters in displayed text or labels should be at least 16 minutes of arc (4.7 mrad) and the maximum character height should be 24 minutes of arc (7 mrad). Character heights of 20-to-22 minutes of arc (5.5-to-6.5 mrad) are preferred for reading tasks. Slightly smaller characters are acceptable in high-contrast displays. Characters should not be larger than 45 minutes of arc (13 mrad) when groups of characters are displayed. Minutes of arc can be converted into height as follows:

$$\text{Height} = 6.283\,(D)(MA)\,/\,21600$$

where MA is minutes of arc and D is the distance from the user to the screen.

3.6.3 Size coding should be used only for applications where displays are not crowded.

3.6.4 When the symbol size is to be proportional to the information value, the scaled parameter should be the symbol area rather than a linear dimension such as diameter.

3.6.5 When character size is variable, design the incremental cursor positioning to vary correspondingly, with a step size matching the size of currently selected characters.

3.6.6 The cursor may take various forms on a graphics display. Many designers recommend a plus-sign for this purpose, representing abbreviated cross-hairs whose intersection can mark a position with reasonable precision. In some applications, it may help to extend the cross-hairs the full height and width of the display. In some applications, it may help to display a cursor incorporating the current values of various attributes (color, size, etc.) that can be selected by a crewmember.

3.6.7 Ensure the means for controlling the size, location, and characteristics of window overlays is consistent from one display to another for each type of overlay.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **3.0 Information Coding** **Category:** **3.6 Size/Symbol**

**References:**

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (3.6.1, 3.6.2)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (3.6.1, 3.6.2, 3.6.3, 3.6.4)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (3.6.1, 3.6.3, 3.6.5, 3.6.6)

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (3.6.1)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (3.6.7)

**Example:**

3.6.1 An increase in symbol height should be accompanied by a proportional increase in width to preserve a constant aspect ratio and facilitate symbol recognition.

3.6.3 Size coding is achieved by varying the size of displayed alphanumerics, labels, and other symbols. Perhaps as many as five sizes might be used for information categorization, but two or three will probably prove the practical limit.

3.6.4 Crewmember judgment of symbol "size" corresponds more closely to its area than its diameter.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Measure symbol size using optical comparator or other suitable equipment. Evaluate size coding methods under typical cockpit environmental and operational conditions with a representative crewmember population. (3.6.1 through 3.6.7)

THIS PAGE INTENTIONALLY LEFT BLANK

**Functional Area: 4.0 Enhancement Coding**

4.1 Brightness/Highlighting
4.2 Blinking/Flashing
4.3 Reverse Video (Brightness Inversion)
4.4 Warning/Caution/Advisory

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **<u>4.0</u> Enhancement Coding** **Category:** **<u>4.1</u> Brightness/Highlighting**

**Rationale:**

Brightness (or contrast) enhancement is a useful technique for providing visual distinction between different classes of information. The method simply involves displaying items at different luminance levels and is often used in displaying alphanumeric information. Brightness and saturation can be used when it is necessary to draw attention to critical information. These enhancements should be easily recognizable and used to attract crewmember attention to special conditions, items important to decision-making or action requirements, or as a means to provide feedback.

**Guidelines:**

4.1.1 Highlighting information should be minimized. Use brightness intensity coding only to differentiate between an item of information and adjacent information. No more than two levels of brightness should be used and should discriminate only between two categories (bright and dim), and each level should be separated from the nearest by at least a 2:1 ratio. (Although saturated and/or intense hues are useful for drawing a crewmember's attention, their overuse will result in a display which is garish and difficult to view for long periods.)

4.1.2 Brightness intensity coding should be used to differentiate between adjacent items of information or code two to three state conditions. Brightness coding should have only one meaning, and a particular highlighting method should be used consistently. Highlighting methods associated with emergency conditions should not also be used in association with normal conditions.

4.1.3 When a critical passage merits emphasis to set it apart from other text, highlight that passage by bolding/brightening, color coding, or by some auxiliary annotation, rather than by capitalization.

4.1.4 For transilluminated displays, such as lighted alarm tiles, the brightest state should be no more than 300% brighter than the inactivated state, and the dim state should be at least 10% brighter than the inactivated state.

4.1.5 High brightness levels should be used to signify information of primary importance and lower levels to signify information of secondary interest.

4.1.6 Brightness coding should not be used in conjunction with shape or size coding.

4.1.7 When an operation is to be performed on a single item on a display, the item should be highlighted.

4.1.8 On crowded displays, codes such as dim labels and bright information should be used to distinguish the labels.

4.1.9 In a list, the option(s) selected by the crewmember should be highlighted.

4.1.10 No more than 10% of the display should be highlighted at one time.

4.1.11 Maximum contrast should be provided between those items highlighted and those not.

4.1.12 Because brightness is also a depth cue (bright objects are viewed as nearer), comodulate luminance with stereopsis.

4.1.13 Ensure that color-coded symbols have a minimum luminance of 1 ft-L.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **4.0 Enhancement Coding** **Category:** **4.1 Brightness/Highlighting**

**References:**

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (4.1.1)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (4.1.1, 4.1.2, 4.1.4, 4.1.10)

Harrison, J., Janowitz, J., Castronuovo, M., Pilot-Vehicle Interface, Federal Aviation Administration, DOT/FAA/CT-92/21, 1993. (4.1.9)

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985. (4.1.3, 4.1.4, 4.1.5, 4.1.6, 4.1.7, 4.1.8, 4.1.9)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (4.1.2, 4.1.3, 4.1.11)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (4.1.1, 4.1.2)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (4.1.12, 4.1.13)

**Example:**

4.1.1 If highlighting is used to attract crewmember attention, the highlighting technique should be distinctive. If a large portion of a display is highlighted, the highlighting will no longer be distinctive.

4.1.2 Brightness coding should have only one meaning (e.g., On-Off or Fast-Slow, or Standby-Run, but not all three).

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the code is detectable. Check for background visual coding which masks its perceptibility. Evaluate the visual display for discriminability from the visual coding alphabet. Ensure compatibility with night vision imaging systems (NVIS). (4.1.1 through 4.1.13)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 4.0 **Enhancement Coding** | **Category:** 4.1 **Brightness/Highlighting**

**Guidelines (continued):**

4.1.14 The level of ambient illumination directly affects the perceived brightness and hue of a color. Consider the following when designing a color display:

- Green provides good general visibility over a broad range of intermediate luminances.
- Yellow provides good general visibility over a broad range of luminances.
- Red is acceptable under high ambient lighting but not in low lighting.

4.1.15 If highlighting is used to emphasize important display items, it should be removed when it no longer has meaning. If highlighting identifies an error, that highlighting should be removed when the error is corrected.

4.1.16 Levels approximating 33% and 100% of the display luminance should be used for brightness coding. The intensities used should not be less than 6 ft-L (20 cd/m$^2$). Intensity coding should not be used for displays with a maximum display luminance of less than 18 ft-L (60 cd/m$^2$) or more than 29 ft-L (100 cd/m$^2$).

4.1.17 Contrast should be either light on a dark background or vice versa, except where superposition is used. For subtractive superposition (at the source), data should be presented as dark markings on a transparent background. For additive superposition (at the screen), data should be presented as light markings on an opaque background.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **4.0 Enhancement Coding** **Category:** **4.1 Brightness/Highlighting**

**References:**

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (4.1.15, 4.1.16, 4.1.17)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (4.1.14 through 4.1.17)

**Example:**

4.1.17 Colored markings against colored backgrounds of comparable brightness should be avoided.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the code is detectable. Check for background visual coding which masks its perceptibility. Evaluate the visual display for discriminability from the visual coding alphabet. Ensure compatibility with night vision imaging systems (NVIS). (4.1.14 through 4.1.17)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **4.0 Enhancement Coding** | **Category:** **4.2 Blinking/Flashing**

**Rationale:**

Crewmembers in a digital cockpit exist in an information rich environment. The challenge for designers is to organize and present this information in a meaningful and accessible manner. During abnormal conditions, crewmembers do not have time to select critical information from that which is unimportant. Blink/flash coding attracts crewmember attention to particular items of information by enhancing the specific character, label, or field representing the relevant information. Indiscriminate use of blink/flash coding may be an annoyance to the crewmember. In determining blink/flash rate, one that is too low may not be immediately recognized by the crewmember; when blink/flash rates are too high, it may be imperceptible by the crewmember.

**Guidelines:**

4.2.1 Blinking/flashing codes should be used for alarms, emergency conditions, or similar situations requiring immediate crewmember action.

4.2.2 Blinking/flashing codes should be used in target detection tasks, particularly with high-density displays.

4.2.3 Provide a means for suppressing the blink/flash action once the coded information has been located.

4.2.4 The blink/flash rate should enable the crewmember to scan the item, but should not be used for coding text that must be read. Blinking characters may have somewhat reduced legibility and may cause visual fatigue if used too much. When blink/flash coding is used to mark information that must be read, an extra symbol (such as an asterisk) should be added as a blinking marker, rather than blinking the information itself.

4.2.5 A 3-to-5 Hz blink/flash rate should be used to attract attention to the item. (Refer to Category 4.4.)

4.2.6 Flashing should only be used as an alerting/warning code, not as a means to highlight routine information. If used sparingly, flashing symbols are effective in calling a user's attention to displayed items of unusual significance. Flash coding generally reduces search times, especially in dense displays.

4.2.7 No more than two different blink/flash rates should be used.

4.2.8 Blink/flash coding should be limited to small fields.

4.2.9 When two blink/flash rates are used, the fast blink/flash rate should approximate four per second and the slow rate should be one blink per second.

4.2.10 When two blink/flash rates are used, the higher rate should apply to the most critical information.

4.2.11 The ON time of a blink/flash shall be approximately equal to the OFF time (minimum ON time of 50 msec).

4.2.12 An Off condition should never be used to attract attention to a message.

4.2.13 Blinking/flashing presentations which could be simultaneously active should have synchronized flashes. (Refer to Category 4.4.)

4.2.14 If a display has a freeze capability, the display should have an obvious reminder that it is in the freeze mode. This information should be provided the crewmember in an attention grabbing mode, such as with a flashing message.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **4.0 Enhancement Coding** **Category:** **4.2 Blinking/Flashing**

**References:**

Harrison, J., Janowitz, J., Castronuovo, M., Pilot-Vehicle Interface, Federal Aviation Administration, DOT/FAA/CT-92/21, 1993. (4.2.1, 4.2.2, 4.2.4, 4.2.6)

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985. (4.2.1, 4.2.3, 4.2.7, 4.2.8, 4.2.9, 4.2.10, 4.2.11, 4.2.12, 4.2.13, 4.2.14)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (4.2.3, 4.2.4)

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (4.2.5, 4.2.7, 4.2.11, 4.2.14)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (4.2.1, 4.2.3, 4.2.4, 4.2.5, 4.2.7, 4.2.9)

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992. (4.2.4, 4.2.10)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (4.2.4, 4.2.7)

**Example:**

4.2.1 Use a blinking/flashing symbol to annunciate an imminent aircraft system failure.

4.2.2 Use a blinking/flashing symbol to designate an uncorrelated hostile target.

4.2.6 Use a flashing landing gear handle light to indicate an unsafe landing gear condition.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the code is detectable. Check for background visual coding which masks its perceptibility. Signals with different meanings should not appear identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Ensure compatibility with night vision imaging systems (NVIS). (4.2.1 through 4.2.14)

## *SA IMPROVEMENT GUIDELINE*

| **Functional Area:** 4.0 **Enhancement Coding** | **Category:** 4.3 **Reverse Video (Brightness Inversion)** |
|---|---|

**Rationale:**

Reverse video ("brightness inversion," where dark characters on a bright background can be changed under computer control to bright on dark, or vice versa) may be used for highlighting critical items that require crewmember attention. When used for alerting purposes, reverse video should be reserved consistently for that purpose and not be used for general highlighting. Reverse video is obviously limited to a two-valued code, i.e., a displayed item is either shown with standard or inverted brightness.

**Guidelines:**

4.3.1 Reverse video should be used primarily for highlighting in dense information fields.

4.3.2 Reverse video should be used to code annunciator information that requires immediate response.

4.3.3 Maximum contrast should be provided between highlighted and nonhighlighted items.

4.3.4 When used for alerting purposes, reverse video should be reserved consistently for that purpose and not be used for general highlighting.

4.3.5 A block cursor might employ reverse video to show any other character that it may be marking.

4.3.6 Use reverse video sparingly. Although effective in making information stand out, reverse video can reduce legibility and increase eye fatigue.

## *SA IMPROVEMENT GUIDELINE*

| | |
|---|---|
| **Functional Area:** **4.0 Enhancement Coding** | **Category:** **4.3 Reverse Video (Brightness Inversion)** |

**References:**

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985. (4.3.1)

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986. (4.3.3, 4.3.5)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (4.3.2, 4.3.4)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (4.3.4)

Defense Information Systems Agency (DISA), User Interface Specifications For The Defense Information Infrastructure (DII), Version 2.0 Preliminary Draft, December 31, 1995. (4.3.5)

Defense Information Systems Agency, User Interface Specifications for the Global Command and Control System (GCCS) Version 1.0, October 1994. (4.3.6)

**Example:**

4.3.1 Image reversal could pinpoint a word or phrase in a paragraph of text, a set of characters in a table of information, or a symbol denoting prioritized information.

4.3.2 Image reversal could signal an incoming message arriving via data link.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Examine the coded information to ensure that legibility is not hindered and that there is no perceptible flicker induced by the reverse image. Ensure that the intended meaning of the coding is clear and immediately understood by the crewmember without ambiguity. Ensure compatibility with night vision imaging systems (NVIS). (4.3.1 through 4.3.6)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 4.0 **Enhancement Coding** | **Category:** 4.4 **Warning/Caution/Advisory**

**Rationale:**

The design of an effective alerting system should provide visual alerts which can be detected and understood easily under high altitude, high ambient light, and critical (i.e., high-G, high workload, high stress) conditions. Visual signals should be presented and located to provide effective luminance contrast and to minimize the effect of excessive ambient light. Specific warning/caution/advisory signals should be based on the aircraft's subsystems, the consequences to safe flight or failures of particular subsystems, aircraft roles, and missions, and crewmember information requirements. Warning/caution/advisory should not be actuated by transient, inappropriate, erroneous, or random sensor signals.

**Guidelines:**

4.4.1 The Warning/Caution/Advisory signals should have sufficient luminance and contrast to be fully readable and easily recognizable in a 10,000 fc lighting environment.

4.4.2 Flashing presentations should be avoided; however, where they are required for their alerting value, they should have a flash rate between 3 to 5 Hz. (Refer to Category 4.2.)

4.4.3 Flashing presentations which could be simultaneously active should have synchronized flashes. (Refer to Category 4.2.)

4.4.4 A single test switch should be provided for testing dedicated visual displays. The test of audible alerts may be incorporated into this test of visual alerts. A test switch is not necessary if the function is automated within an integrated alert display.

4.4.5 The visual master warning/master caution signal should remain ON until it is canceled by the crewmember or canceled automatically when the problem is corrected, and so long as no other alerts remain active.

4.4.6 Master caution, master warning, master advisory, and summation lights used to indicate the condition of an entire subsystem should be set apart from lights which show status of the subsystem components. Indicator lights used solely for maintenance and adjustment should be covered or nonvisible during normal equipment operation, but should be readily accessible when required. Lights and related indicators should be used sparingly and should display only that information necessary for effective system operation.

4.4.7 Locate error and status messages consistently in a dedicated area of the display. Emphasize these messages using a contrasting display feature (e.g., reverse video, highlighting, or preceding series of unique symbols, such as asterisks).

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **4.0 Enhancement Coding** **Category:** **4.4 Warning/Caution/Advisory**

**References:**

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (4.4.6)

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (4.4.7)

**Example:**

4.4.3 Warnings of concurrent low fuel pressure and low fuel quantity should flash simultaneously.

4.4.6 The electrical system master advisory light should not be colocated with the No. 2 generator failure light.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the code is detectable and easily understood. Ensure night vision imaging systems (NVIS) compatibility. Ensure that color coding schemes conform to those identified in 4.4.8. (4.4.1 through 4.4.7)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **4.0 Enhancement Coding** **Category:** **4.4 Warning/Caution/Advisory**

**Guidelines (continued):**

4.4.8 Transilluminated displays should conform to the following color coding scheme, in accordance with Type I - Aviation colors of MIL-C-25050:

a. RED should be used to alert an operator that the system or any portion of the system is inoperative, or that a successful mission is not possible until appropriate corrective or override action is taken. Examples of indicators which should be coded RED are those which display such information as "no-go," "error," "failure," "malfunction," etc.

b. FLASHING RED should be used only to denote emergency conditions which require operator action to be taken without undue delay, or to avert impending personnel injury, equipment damage, or both.

c. YELLOW should be used to advise an operator that a condition exists which is marginal. YELLOW should also be used to alert the operator to situations where caution, recheck, or unexpected delay is necessary.

d. GREEN should be used to indicate that the monitored equipment is in tolerance or a condition is satisfactory and that it is all right to proceed (e.g., "go-ahead," "in-tolerance," "ready," "function activated").

e. WHITE should be used to indicate system conditions that do not have "right" or "wrong" implications, such as alternative functions (e.g., Missile No. 1 selected for launch, etc.) or transitory conditions (e.g., action or test in progress, function available), provided such indication does not imply success or failure of operations.

f. BLUE may be used for an advisory light, but preferential use of BLUE should be avoided.

4.4.9 When a transilluminated indicator is associated with a control, the indicator light should be located so that it can be associated with the control without error and should be visible to the crewmember during control operation. For critical functions, indicators should be located within 265 mrad (15 deg) of the crewmember's normal line of sight. Warning lights should be an integral part of, or located adjacent to, the lever, switch, or other control device by which the crewmember is to take action.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 4.0 **Enhancement Coding** **Category:** 4.4 **Warning/Caution/Advisory**

**Reference:**

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (4.4.8, 4.4.9)

**Example:**

4.4.9 Placing the unsafe landing gear warning light in the landing gear handle (as in the P-3) falls into this category.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual displays under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the code is detectable and easily understood. Ensure night vision imaging systems (NVIS) compatibility. Ensure that color coding schemes conform to those identified in 4.4.8. (4.4.8, 4.4.9)

THIS PAGE INTENTIONALLY LEFT BLANK

**Functional Area: 5.0 Auditory Coding**

5.1 General
5.2 Warning/Caution/Advisory
5.3 Voice Annunciation (Speech Coding)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 5.0 Auditory Coding** **Category: 5.1 General**

**Rationale:**

Auditory signals provide rapid alerting irrespective of head position or eye fixation. They are quickly perceived and are useful in situations where vision is likely to be degraded. Audio signals should be provided when:

- The information to be presented is short, simple, and transitory, requiring immediate or time-based response.
- Vision is restricted or degraded by ambient light variability, vibration, high G forces, hypoxia, etc.
- Information criticality makes supplementary or redundant transmission desirable.
- Custom or use has created the expectation of an audio display.

**Guidelines:**

5.1.1 Ensure compatibility of audio signals with ambient cockpit noise conditions. Audio signals should not startle crewmembers, add to overall noise levels, or interfere with local speech activity.

5.1.2 Associate a unique audio signal with a unique operating situation. The same signal should designate the same information at all times.

5.1.3 Avoid conflict with previously used signals.

5.1.4 The system should be designed to minimize the effects of undetected, false, inappropriate, or spurious alerts, or any condition which would cause a crewmember to perceive an audible alert signal when no warning, caution, or abnormal advisory condition exists.

5.1.5 Design audio signals with BIT or other means of operability testing which will provide a level of confidence to the crewmember that the audio signals are functional. The crewmember should have a means for selecting either a representative subset or the entire set of audible annunciations for testing. This test function may be incorporated with the visual alerts test function. A BIT verification of proper audio system operation should be provided at system initialization and during system operation.

5.1.6 Where feasible, audio signals should exploit learned or natural relationships of the crewmember, leading to increased comprehension and understanding of the signal.

5.1.7 Audio signals should provide only information necessary for the crewmember.

5.1.8 Do not overload the auditory channel (only a few signals should be used in any given situation). Too many signals can confuse and overload the crewmember.

5.1.9 Consider two stage signals when complex information is presented. The signal stages would consist of:

- Attention demanding signal: attracts attention and identifies a general category of information.
- Designation signal: follows the attention demanding signal and designates the precise information within the general class indicated by the first signal.

5.1.10 Limit the use of one audio signal in conjunction with several visual displays except where immediate discrimination is not critical to personnel safety or system performance. (Indiscriminate use of audio signals can result in auditory clutter and misinterpretation of information.)

5.1.11 Where feasible, interrupted or variable audio signals should be used rather than steady-state audio signals.

5.1.12 Use three-dimensional audio (3-D Audio) cueing properties to increase situational awareness of attitude, threats, and terrain.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 5.0 Auditory Coding** **Category: 5.1 General**

**References:**

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (5.1.1)

McKinley, R. L., Erikson, M. A., D'Angelo, W. R., 3-Dimensional Auditory Displays: Development, Applications, and Performance, Aviation, Space and Environmental Medicine, 1994. (5.1.12)

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (5.1.4, 5.1.5)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (5.1.4, 5.1.5, 5.1.10)

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985. (5.1.2)

Sanders, M. S., McCormick, E. J., Human Factors in Engineering and Design, Seventh Edition, McGraw-Hill, Inc., 1993. (5.1.3, 5.1.6, 5.1.7, 5.1.8, 5.1.9, 5.1.11)

Woodson, W. E., Human Factors Design Handbook, New York: McGraw-Hill, 1981. (5.5.1)

**Example:**

5.1.1 A speech annunciated display superimposed over a radio or ICS transmission would be difficult to interpret. High intensity signals can cause a startle response and actually disrupt performance.

5.1.2 The use of the same audio signal to signify an unsafe landing gear indication and a hydraulic system malfunction could cause misinterpretation, confusion, and possible loss of the aircraft.

5.1.3 Newly installed signals should not contradict in meaning similar signals used in existing or earlier systems.

5.1.4 A Radar Warning Receiver audio display which provides confidence levels to improve system/crewmember performance.

5.1.6 The use of a rapidly repeating audio signal to denote situation urgency is an example.

5.1.8 During the Three Mile Island nuclear crisis, over 60 different auditory warning signals were activated.

5.1.10 A single tone to provide alert for avionics systems status changes, for example.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the audio displays under varying cockpit environmental and operational conditions with a representative crewmember population to test for false alarms. Ensure that the code is detectable. Check for background noises which mask its perceptibility. Signals with different meanings should not sound identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Ensure that unique audio signals are used. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that a single tone is not used for more than one visual display in critical warning situations. (5.1.1 through 5.1.12)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 5.0 Auditory Coding** | **Category: 5.1 General**

**Guidelines (continued):**

5.1.13 Detectability of a tone in noise is affected by duration of the signal as well as the signal-to-noise (S/N) ratio (the relative power of the signal). For signal durations below approximately 200 msec, sensitivity decreases linearly as duration decreases (i.e., the S/N ratio necessary to maintain signal audibility increases as duration decreases). Increasing signal duration beyond 200 msec has only a small effect on signal detectability.

5.1.14 The frequency of an audio signal should be within the range of 200 to 5000 Hz, and preferably between 500 to 3000 Hz (because the ear is most sensitive to this middle range).

5.1.15 Audio signal duration should be at least 0.5 sec and should continue until the appropriate response is made.

5.1.16 A volume control should be provided to individual crewmembers to allow individual crewmember adjustment of the auditory presentation level of audible alerts, within limits that will ensure minimum and maximum S/N ratios. The presentation level at the crewmember's ear should be referenced to the cockpit noise level at the crewmember's ear and should be over a range of 0 dB S/N ratio to +30 dB S/N ratio with individual crewmember selectable levels at 3 dB or smaller increments.

5.1.17 An integrated system of presentation for audible alerts, including systems alerts, flight parameter alerts, and tactical alerts, should be provided so as to present alerts in a consistent method, in order of urgency, and without causing crewmember auditory overload.

5.1.18 Audible normal advisory feedback should be provided for control inputs made under circumstances that may prevent crewmembers from observing visual feedback normally presented in response to those control inputs. Audible normal advisory feedback should be integrated with audible alerts so as not to cause crewmember auditory overload.

5.1.19 A visual indication should always be required in conjunction with any audible or tactual alert due to the transient nature of the audible and tactual modes of signal presentation.

5.1.20 A small number of sounds, up to a maximum of five, may be used for warnings provided these sounds exhibit high levels of sound imagery, are not confused with other sounds that occur in the cockpit or with one another, and are learnable with a single exposure to the sound in the same way that a spoken word is recognized immediately by a crewmember.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 5.0 Auditory Coding** **Category: 5.1 General**

**References:**

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (5.1.13)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (5.1.13, 5.1.14, 5.1.15)

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (5.1.16, 5.1.17, 5.1.18, 5.1.19, 5.1.20)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (5.1.14)

**Example:**

5.1.15 Completion of a corrective action by the crewmember or by other means should automatically terminate the signal.

5.1.17 An audible engine fire alert, hydraulic system alert, and missile warning alert should emanate from a single, coordinated and prioritized audio alerting system.

5.1.18 System confirmation of a HOTAS switch activation while the crewmember conducts a head-up out-of-the-cockpit visual search, for example.

5.1.19 An audible electrical system alert accompanied by a master electrical caution light is an example of this principle.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the audio displays under varying cockpit environmental and operational conditions with a representative crewmember population to test for false alarms. Ensure that the code is detectable. Check for background noises which mask its perceptibility. Signals with different meanings should not sound identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Ensure that unique audio signals are used. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that a single tone is not used for more than one visual display in critical warning situations. (5.1.13 through 5.1.20)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **5.0 Auditory Coding** | **Category:** **5.2 Warning/Caution/Advisory**

**Rationale:**

Auditory signals provide rapid alerting irrespective of head position or eye fixation. They should be used when it is desirable to warn, alert, or cue the crewmember. Judicious use of auditory signals for these functions can enhance crewmember performance and mission effectiveness. Speech is the preferred encoding method for warnings because speech messages can convey explicit information about hazardous conditions without the need for the crewmember to refer immediately to a visual display and because speech messages use a code already known to the crewmember. This is in contrast to the relative arbitrary assignment of meanings to warning sounds, which must be learned.

**Guidelines:**

5.2.1 The design of an effective audible alerting system should satisfy the following functional requirements:

- Audible or visible warning, caution, or abnormal advisory alerts should not be provided when all systems are operating normally.
- Audible alerts should reduce user information assimilation and memory demands and minimize the time required for the user to detect and assess failure conditions and initiate corrective actions.
- Audible alerts should be detectable and understood quickly and easily under high altitude, high ambient noise, heavy radio traffic, heavy crew voice communications, and critical (i.e., high-G, high workload, high stress) conditions.
- An audible alerts system should integrate flight parameter and tactical alerts into a single system.
- Audible alerts should facilitate alerting system standardization.
- Audible alerts should provide for alerting system growth capability in a form that does not necessitate additional system components.

5.2.2 Use auditory signals in conjunction with visual Warning/Caution/Advisory signals.

5.2.3 If different warning signals are used to represent different conditions requiring different responses, each should be discriminable from the others, and moderate intensity signals should be used. If modulation of the frequency (Hz) of a signal denotes information, center frequencies should be between 500 and 1000 Hz.

5.2.4 Where masking is a critical factor, warning signals should be concentrated in frequency bands that are unused or little used by primary communications.

5.2.5 Where warning signals delivered to headsets might mask other essential auditory signals, separate channels may be provided to direct the warning signal to one ear and the background signal to the other ear.

5.2.6 Audio warning signals should be at least 10 dB above the loudest expected ambient noise level.

5.2.7 For warning signals, use a modulated signal (1 to 8 beeps per second, or warbling sounds varying from 1 to 3 times per second), since it is different enough from normal sounds to demand attention.

5.2.8 Caution signals should be readily distinguishable from warning signals and should be used to indicate conditions requiring awareness, but not necessarily immediate action. If the audio signal varies on one dimension only (such as frequency), the number of signals to be identified should not exceed four.

5.2.9 Audible portions of alerting signals should be automatically canceled within 3 sec if not previously canceled by aircrew. Upon cancellation, the master warning/caution signal should reset automatically to be able to annunciate new alerting situations, including any which occurred prior to cancellation but were waiting to be annunciated to the aircrew.

## *SA IMPROVEMENT GUIDELINE*

| **Functional Area:** 5.0 Auditory Coding | **Category:** 5.2 Warning/Caution/Advisory |
|---|---|

**References:**

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (5.2.4, 5.2.6)

Sanders, M. S., McCormick, E. J., Human Factors in Engineering and Design, Seventh Edition, McGraw-Hill, Inc., 1993. (5.2.3, 5.2.5, 5.2.7)

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (5.2.2, 5.2.8)

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (5.2.1, 5.2.9)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (5.2.3, 5.2.8)

**Example:**

5.2.2 Audio and visual cues should alert the pilot of a high angle of attack condition which could lead to uncontrolled flight.

5.2.5 Presenting missile warning auditory cues to the left ear while presenting communications traffic to the right ear is an example of this principle.

5.2.6 The intensity level should be set so that it is not masked by the cockpit ambient noise level.

5.2.9 Automatically canceling the audible fire warning cue after 3 sec while continuing the visual alert (engine fire warning light) is an example of this principle.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the audio displays under varying cockpit environmental and operational conditions with a representative crewmember population to test for false alarms. Ensure that the code is detectable. Check for background noises which mask its perceptibility. Signals with different meanings should not sound identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Ensure that unique audio signals are used. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that a single tone is not used for more than one visual display in critical warning situations. (5.2.1 through 5.2.9)

## SA IMPROVEMENT GUIDELINE

**Functional Area:** 5.0 **Auditory Coding** **Category:** 5.2 **Warning/Caution/Advisory**

**Guidelines (continued):**

5.2.10 A distinctive voice that is distinguishable from all other voices heard in the aircrew station should be used for speech alerts.

5.2.11 The intelligibility of spoken alerts should be such that each message is recognized correctly the first time it is heard in an actual operational acoustic environment.

5.2.12 Speech message wording should use phraseology familiar to the crewmembers that will hear the messages and should conform to the following detailed requirements:

- Conform as closely as possible with natural language grammar.
- Use polysyllabic words where possible to maximize intelligibility.
- Contain a minimum of four syllables in the complete message.
- Be presented at a speaking rate of 180 $\pm$20 words per minute.
- Be presented in a mechanical sounding and highly intelligible voice that is distinct from other voices heard in the cockpit, and which has a baseline fundamental frequency or voice pitch of 160 $\pm$10 Hz.
- Use speech rhythm with individual word stress, pause locations, and pause durations appropriate for the selected speech rate and syntactic context.
- Be spoken no more than once per occurrence of a new warning.

5.2.13 Speech warning messages may contain an alerting stimulus, such as an attenson (a sound which by virtue of its acoustic characteristics attracts the attention of the crew), alerting word, intonation, or voice quality, but only to improve overall aircrew speed or accuracy in response to hazardous situations requiring immediate action.

5.2.14 Warning sounds should exhibit high sound imagery, that is, the sound itself should sound like what it means. Any sound used for warnings must be learnable by the crewmember with a single exposure to the sound or already well known to the crewmember through prior flight experience.

5.2.15 Three warning sounds have widespread prior use in various types and categories of aircraft:

- *Master Warning Sound* - The Master Warning Sound should produce an output with the following frequency and interruption rates: Fundamental audible output frequency should sweep from 700 to 1700 Hz in 0.85 sec, with an interruption interval of 0.12 sec.
- *Bail-Out Signal* - The audible bailout sound for use in troop carriers, cargo transport, and all other multicrew aircraft should be a bell. The bell should strike at a continuous rate of 5 $\pm$ 1 beats per second and should be audible to all crewmembers and passengers during flight.
- *Wheels-Up Signal* - An audible wheels-up sound should have a fundamental tone frequency of 250 $\pm$50 Hz, interrupted at 5.0 $\pm$ 1.0 Hz with a 50 $\pm$ 10% on-off cycle.

5.2.16 The total number of sound alerts should be limited by two factors: (1) ability of the crewmember to discriminate among sound alerts easily, quickly, and without confusion and (2) consideration of the expected frequency of occurrence of sound alerts during operational flight and the overall density of speech and sound in the cockpit.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 5.0 Auditory Coding** **Category: 5.2 Warning/Caution/Advisory**

**Reference:**

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (5.2.10, 5.2.11, 5.2.12, 5.2.13, 5.2.14, 5.2.15, 5.2.16)

**Example:**

5.2.13 An alerting word may be used before the actual warning message: "Fire, left engine fire!"

5.2.14 An audible engine fire warning consisting of a fire-truck siren-like tone is an example of this principle.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate audio displays under varying cockpit environmental and operational conditions with a representative crewmember population to test for false alarms. Ensure that the code is detectable. Check for background noises which mask its perceptibility. Signals with different meanings should not sound identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Ensure that unique audio signals are used. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that a single tone is not used for more than one visual display in critical warning situations. (5.2.10 through 5.2.16)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **5.0 Auditory Coding** **Category:** **5.3 Voice Annunciation (Speech Coding)**

**Rationale:**

Audible alert signals may be spoken messages or sounds. The selection of encoding method, speech or sounds, depends on the urgency and type of information being conveyed. Information types include warnings, cautions, abnormal advisories, normal advisories, and control input feedback. Speech is the strongly preferred encoding method for warnings because it conveys explicit information without immediate crewmember reference to a visual display and because speech messages use a code already known to the crewmember. (Refer to Category 5.2.)

**Guidelines:**

5.3.1 Speech encoding may be used for the following types of information:

- Warnings.
- Cautions.
- Normal advisories only if the advisory information merits immediate crewmember awareness of the change from dangerous condition to a not dangerous condition.
- Immediate normal advisory feedback of control inputs in situations where the crewmember needs immediate awareness of control input results, but cannot divert attention to look at the control status display.
- Advisory responses to crewmember queries if the crewmember, upon requesting information, cannot divert attention to a visual display. Otherwise, a visual display only should be used to provide such information.

5.3.2 The audible alert signal, whether speech or sound, for a given occurrence for an alerting condition should have a duration no less than 0.5 sec and no longer than 3.0 sec.

5.3.3 A visual indication should be provided in conjunction with each audible systems warning, caution, and advisory signal and should remain displayed after the audible alert is annunciated until the crewmember acknowledges the alert or the alert condition no longer exists. For tactical and flight parameter alerts, a visual indication should be provided in conjunction with each audible alert and should remain displayed after the audible alert has been annunciated until the alert condition no longer exists. Neither visual nor auditory tactical alerts nor flight parameter alerts should customarily be subject to acknowledgment by the crew.

5.3.4 Words selected should be concise, intelligible, and appropriate to the task/information presented.

5.3.5 Where possible, words that rhyme and may confuse message interpretation should not be part of the spoken lexicon, or should not be presented within the same message.

5.3.6 Spoken messages should be presented in a formal, impersonal manner. Avoid the use of slang.

5.3.7 Words with more than one syllable should be used.

5.3.8 Alphanumeric data should be presented using phonetic alphabets.

5.3.9 Spoken messages should be produced in the form of the average talker with a distinctive and mature voice using an American English accent without regional dialects. Messages should be brief, informative, and to the point.

5.3.10 Speech intensity should be appropriate to the expected ambient noise environment. Signal-to-noise ratios should be at least 5:1. Speech signals should fall within the range of 200 to 6100 Hz.

5.3.11 Spoken warning messages should be preceded by an alerting signal. Crewmembers should be required to acknowledge spoken warning signals.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 5.0 Auditory Coding** **Category: 5.3 Voice Annunciation (Speech Coding)**

**References:**

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (5.3.1, 5.3.2, 5.3.3)

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989. (5.3.4 through 5.3.11)

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994. (5.3.6, 5.3.7, 5.3.8, 5.3.9)

**Example:**

5.3.8 "Whiskey Zulu three two seven" should be used in preference to "WZ327" where the "Z" and "3" are phonetically similar.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate voice displays under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the voice display is detectable. Check for background noises which may mask its intelligibility and perceptibility. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that the intended meaning of the voice display is clear and immediately understood by the crewmember without ambiguity. (5.3.1 through 5.3.11)

THIS PAGE INTENTIONALLY LEFT BLANK

**Functional Area: 6.0 Environmental Stressors**

6.1 Noise
6.2 Temperature/Heat/Humidity
6.3 Flight Clothing
6.4 Acceleration/High G
6.5 Fatigue

## *SA IMPROVEMENT GUIDELINE*

| | |
|---|---|
| **Functional Area: 6.0 Environmental Stressors** | **Category: 6.1 Noise** |

**Rationale:**

Noises generated by various aircraft components and perceived by crewmembers in the cockpit are collectively considered background noise. Studies show that the effects of background noise on crewmember performance varies with the individual and the tasks to be carried out. It is generally accepted that noise contributes to feeling of stress. As a result, several analyses have been conducted to see how various noise levels affect crewmember performance of typical tasks. Military standards exist regarding the intensity of equipment noise. Tests have shown that even the background noise that does not affect overall performance can still influence the way crewmembers may prefer to extract necessary information. When choosing how to display information, designers should take this change in preference into account. (Refer to MIL-STD-1294, Acoustical Noise Limits in Helicopters.)

**Guidelines:**

6.1.1 Background noise should ideally be kept at around 40 to 50 dB level. It should not exceed 80 dB, as this level has been shown to draw strong complaints from people in confined areas. At 85 dB, one can expect cognitive performance decrements.

6.1.2 Background noise should not mask auditory signals or messages.

6.1.3 Avoid sudden loud noise bursts that are infrequent, occur at irregular intervals, or are unexpected as they may distract crewmembers and cause performance errors in high concentration tasks.

6.1.4 High frequency tones (>8000 Hz) should not be present in background noise.

6.1.5 While some noise has been shown to improve performance for certain tasks, distracting noises should be eliminated or masked.

6.1.6 Sound levels should be adjustable, when possible, to compensate for crewmember hearing decrement. However, care should be taken that, in adjusting the sound level, auditory signals or messages do not mask one another or become masked by the background noise.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 6.0 **Environmental Stressors** **Category:** 6.1 **Noise**

**References:**

Woodson, W. E., Human Factors Design Handbook, New York: McGraw-Hill, 1981. (6.1.1)

Bell, P., Fisher, J., Baum, A., and Greene, T., Environmental Psychology, Fort Worth: Holt, Rinehart and Winston, Inc., 1990, Third Edition, 1990. (6.1.3)

Gilmore, W. E., Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, Idaho Falls, Idaho: E G & G Idaho, Inc., July 1985. (6.1.4)

Zhang, K., Wickens, C. D., Effects of Noise and Workload on Performance With Two Object Displays vs. A Separated Display, Proceedings of the Human Factors Society 34th Annual Meeting, 1990. (6.1.5)

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (6.1.2, 6.1.5, 6.1.6)

**Examples:**

6.1.5 Constant, distracting noise from a machine can be masked or lessened by introducing white noise or noise at a lower frequency.

6.1.6 Make the volume of any auditory signal adjustable so the aircrew can choose a sound level they deem appropriate based on the intensity of existing background noise.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the noise level of the cockpit under typical cockpit environmental and operational conditions using audiometric equipment and subjectively with a representative crewmember population. Auditory signals and messages should be evaluated for clarity and perceptibility under all possible circumstances. (6.1.1 through 6.1.6)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **6.0 Environmental Stressors** **Category:** **6.2 Temperature/Heat/Humidity**

**Rationale:**

Air temperature, humidity, and air movement combine to produce the effects of heat. The initial physiological response to heating is vasodilation in the skin, followed by active sweating. Heart rate increases and generalized feelings of lethargy occur, and performance may be adversely affected depending on skin and core temperature. Heating alters sleep patterns, with passive body heating before sleep producing increasing EEG slow wave activity and reducing the amount of REM sleep, while elevated temperature during sleep increases awake activity and incidence of sleep disturbances.

Crewstation temperatures are affected by three general factors: (1) the external environment, (2) crewstation personnel, and (3) the aircraft operating state.

The external environment attempts to add heat to or remove heat from the crewstation. Ambient temperature and direct sunlight are the major contributors to crewstation heat. With no other inputs, the crewstation temperature will eventually match the external ambient temperature. In direct sunlight, the greenhouse effect of many modern canopies causes dramatic temperature increases.

Crewmembers are a heat source radiating at 98.6°F. If active, they generate more heat. If dressed in insulated clothing, they are less tolerant of higher operative temperatures.

There are considerable differences between people with respect to their tolerance to heat stress. Several factors that account for some of these differences include:

- *Physical fitness:* The more physically fit a person is, the greater his or her tolerance to working in hot environments.
- *Aging:* Aging results in more sluggish response of the sweat glands and less total body water.
- *Gender:* Under heat stress, women generally show greater increases in heart rate, lower maximal sweat rates, higher skin temperatures, and, in severe wet heat, higher core temperatures.
- *Body fat:* Excessive body fat means additional weight must be carried, and the body surface-to-body weight ratio becomes less favorable for heat dissipation. The fat also creates an insulating layer between the skin and deep body tissues, thereby hindering heat transfer to the skin and dissipation.

**Guidelines:**

6.2.1 Personal equipment thermal control: When special protective clothing or personal equipment, including full and partial pressure suits, fuel handler suits, body armor, arctic clothing, and temperature regulated clothing are required and worn, a comfort micro-climate between 20°C (68°F), 14 mm Hg ambient water vapor pressure, and 35°C (95°F), 3 mm Hg ambient water vapor pressure is desirable and, where possible, shall be maintained by heat transfer systems.

6.2.2 Degradation of mental and cognitive skills, tracking skills, and dual task performance may be expected as environmental exposure exceeds 85°F effective temperature (ET). Crewstation temperature should be kept between 50°F and 85°F. The temperature differential between floor level and head level should not exceed 10°F. (ET: An index for estimating the effect of temperature, humidity, and air movement on the subjective sensation of warmth.)

6.2.3 For reaction time and mental tasks, increases in either temperature or exposure time are associated with degraded performance. For tracking, vigilance, and complex tasks, increases in temperature cause greater degradations in performance than increased exposure time.

6.2.4 The longer the exposure, the greater the performance decrement until a floor effect is reached at about 3 hr.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **6.0 Environmental Stressors** **Category:** **6.2 Temperature/Heat/Humidity**

**References:**

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (6.2.1, 6.2.2)

Hancock, P. A., Task Categorization and the Limits of Human Performance in Extreme Heat, Motor Behavior Laboratory, University of Illinois at Urbana-Champaign, Champaign, Illinois, 1982. (6.2.2)

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (6.2.3, 6.2.4)

**Example:**

6.2.1 The use of anti-exposure suits, CBR gear, anti-G-suits etc., contribute to crewmember inability to maintain a comfortable personal temperature environment.

6.2.2 Preflight/flight operations above this temperature range may cause crewmembers to rush through checklists, ignore critical warnings, or otherwise experience degraded performance in the accomplishment of their mission.

6.2.3 High tempo tactical flight operations in an extremely hot desert setting could significantly degrade threat awareness.

**Method of Assessment:**

Requires a fully instrumented crewstation. Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Temperature sensors should be located at head, chest and foot level at each crew position. Humidity sensors should also be located at each crew position, with optional sensors located throughout the crewstation. Record and analyze data to ensure compliance with these guidelines. (6.2.1 through 6.2.4)

***SA IMPROVEMENT GUIDELINE***

**Functional Area:** **6.0 Environmental Stressors** **Category:** **6.2 Temperature/Heat/Humidity**

**Guidelines (continued):**

6.2.5 Provide an adequately heated environment. Exposure to cold temperatures may have an effect on performance. Performance of manual tasks is degraded when:

- Hand temperatures are <11°C.
- Control surface temperatures are <15.6°C.
- Cockpit temperatures are <13°C.

6.2.6 Approximately 45% relative humidity should be provided at 21°C (70°F). This value should decrease with rising temperatures, but should remain above 15% to prevent irritation and drying of body tissues, e.g., eyes, skin, and respiratory tract.

6.2.7 Individuals who are skilled on the task they are performing, and are able to use relatively attention-free automatic-type processes, suffer less adverse temperature stress effects than their unskilled peers.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 6.0 Environmental Stressors** **Category: 6.2 Temperature/Heat/Humidity**

**References:**

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated. (6.2.6)

Hancock, P. A., Sustained Attention Under Thermal Stress, American Psychological Association, Inc. Bulletin, Vol. 99, No. 2, 1986. (6.2.7)

Rubin, L. S., Manual Dexterity of the Gloved and Bare Hand as a Function of the Ambient Temperature and Duration of Exposure, Journal of Applied Psychology, 1957. (6.2.5)

Lockhart, J. M., Kiess, H. O., and Clegg, T. J., Effect of Rate and Level of Lowered Finger Surface Temperature on Manual Performance, Journal of Applied Psychology, 1975. (6.2.5)

Teichner, W. H. and Kobrick, J. L., Effects of Prolonged Exposure to Low Temperature on Visual-Motor Performance, Journal of Experimental Psychology, 1955. (6.2.5)

**Example:**

6.2.6 Aircrew may experience symptoms of dehydration when operating in hot and dry environments.

6.2.7 The use of properly designed adaptive automation techniques may lessen the effects of temperature stress.

**Method of Assessment:**

Requires a fully instrumented crewstation. Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Temperature sensors should be located at head, chest, and foot level at each crew position. Humidity sensors should also be located at each crew position, with optional sensors located throughout the crewstation. Record and analyze data to ensure compliance with these guidelines. (6.2.5, 6.2.6, 6.2.7)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 6.0 **Environmental Stressors** **Category:** 6.3 **Flight Clothing**

**Rationale:**

Detailed descriptions of clothing worn by crewmembers, including information about its upkeep and repair, can be found in appropriate military publications. This apparel should be considered when determining permissible ambient temperature levels in the cockpit. Advances being made in equipment worn by crewmembers, such as night vision imaging systems (NVIS) and other helmet mounted displays, narrow crewmember field of vision. Also, certain protective clothing, such as chemical and biological warfare (CBR) gear, alter the heat stress experienced by crewmembers as well as their vision, and thus impact their performance. Even ill-fitting clothes can profoundly influence crewmember state of mind and abilities. Thus, flight clothing should be considered when determining optimum ways to improve crewmember situational awareness, and the design and testing of the crewstation should be made with all possible personal gear worn by the aircrew for the platform in mind.

**Guidelines:**

6.3.1 Flight clothing should be tailored to fit individual crewmembers as much as possible while maintaining flame and immersion protection capability. Ill-fitting flight clothing can distract the aircrew and limit the normal reach of their limbs. As added assurance, controls should be placed within crewmember reach.

6.3.2 Design aircraft systems to compensate for limitations caused by NVIS and/or CBR gear:

- Place necessary cues within the 40 deg field of view (NVIS and CBR).
- Ensure that color codes are distinguishable (NVIS).
- Minimize optical illusions that may be caused by misjudgments of distances to and sizes of external objects (NVIS).
- Limit crewmember exertion to perform the mission required (CBR).

6.3.3 Improve the design of flight clothing and personal flight equipment, particularly anti-G suits, so they can accommodate varying sizes and physiques of crewmembers.

6.3.4 Flight gear should be compatible with personal activities such as drinking water and relief methods. If these activities require crewmember attention, some type of automation should be in place to take over key aircraft functions.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **6.0 Environmental Stressors** **Category:** **6.3 Flight Clothing**

**References:**

Naval Air Technical Services Facility, Aircrew Personal Protective Equipment, Technical Manual for Aviation-Crew Systems, Philadelphia, Pennsylvania. (6.3.1)

Beilman, J. L. and Gawron, V. J., Guidelines for Using Airborne Color Displays, 1985. (6.3.2)

Lind, Judith H., Burge, Carol G., Human Factors Problems For Aircrew-Aircraft Interfaces: Where Should We Focus Our Efforts?, AGARD Conference Proceedings 521, October 1992. (6.3.2)

Ripley, Grady L., Solana, Kathy E., Hill, Ronald C., Female Anti-G Suit Fit and Comfort, SAFE Journal, Vol. 24, No. 2. (6.3.3)

Mlnarik, R., Daily Flight Report: Compatibility of CBR Gear in the AV-8B, NAWC-AD, Patuxent River, Maryland, 10 October 1995. (6.3.2, 6.3.4)

**Examples:**

6.3.1 The shoulders on the flight suit should lie correctly and arm holes should be a comfortable size. If either is too large or small, moving the arm to an upright position, for example, will meet with increased resistance. In anti-exposure suits that have several layers of clothing, this increased resistance will restrict motion and add to crewmember exertion. Exertion contributes to crewmember heat stress, a factor already of concern.

6.3.2 In flight tests conducted at NAWCAD Patuxent River, Maryland, a pilot flying an AV-8B wearing CBR gear reported difficulty seeing the port aileron during the flight control check and expressed the need for an increase in pilot scan because of the loss of binocular vision. During in-flight refueling, the pilot reported the necessity of a 90 deg head turn to obtain adequate 3-D vision to connect the in-flight refueling basket and probe. Sideward glances resulted in misplacement in the left/right direction of the probe.

6.3.3 Issues on the fit of anti-G suits, in particular modifying them for women, are currently being addressed. Suit improvements are being realized as tests on the Navy's Combat Edge G-suit technology show.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Tests of personal flight gear should be conducted in simulators under typical cockpit environmental and operational conditions, followed by actual flight tests to determine if crewmembers can perform flight mission tasks. Flight gear configurations should be determined and tested. Deficiencies should be noted, and appropriate measures should be taken to improve the gear or the aircraft system. (6.3.1 through 6.3.4)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **6.0 Environmental Stressors** **Category:** **6.4 Acceleration/High G**

**Rationale:**

Because of the physiological changes crewmembers experience when their aircraft encounters positive or negative G forces, a high G environment has a profound effect on their performance. The most commonly encountered G force, along the head to foot axis (± Gz), unfortunately, is in the direction to which the human body is most susceptible. The G forces in this direction cause the soft tissues and organs to droop and promote a tendency for blood to pool in the lower body extremities. The changes that occur in blood pressure lead to loss of vision followed by loss of consciousness (termed GLOC, G-induced loss of consciousness). A sustained exposure to high Gz also alters the gas exchange that occurs in the lungs, thus lowering the amount of oxygen transported in the blood. This decrease of oxygen adversely affects brain function. Also, the increased weight of body parts in a high G situation makes extensive head or limb movement nearly impossible. With the trend toward designing increasingly agile aircraft, the high G environment is a prime design consideration.

**Guidelines:**

6.4.1 Because fine movements of the hands and fingers are not greatly affected at high G's, controls that can use these fine movements should be exploited and properly located.

6.4.2 The disadvantages of a heavy helmet are magnified in a high G environment and should be considered when implementing helmet mounted displays.

6.4.3 As aircraft become capable of increased G's, a dramatic cockpit redesign may become necessary for the aircrew to operate the aircraft to its full performance potential.

6.4.4 During the onset of increased G's, head movement becomes difficult and vision undergoes a tunneling effect. Peripheral vision is lost first followed by loss of central vision with continued G exposure. Crewmembers sometimes use this phenomena as an indicator that GLOC is approaching. (If the onset of G's is quick enough, however, the loss of consciousness occurs directly.) Any visual cues vital in this part of the airplane's maneuvering should be placed in the central part of the crewmember's vision. Auditory or tactile cues may be more appropriate because of the loss of visual acuity.

6.4.5 Studies involving rotational accelerations and decelerations suggest that the minimum size of characters on displays for routine applications are too small when experiencing these types of motions. The contrast of the displays may also need to be increased.

6.4.6 Ensure that crewmembers know mission task status and are aware of remaining tasks to be performed when they resume control of an aircraft after recovering from GLOC.

6.4.7 High G's, as well as other flight factors (such as night vision imaging systems), can cause spatial disorientation and vertigo leading to crewmember error. The design of aircraft systems should limit procedures that induce disorientation, include aids to recover from unusual attitudes, and include ground proximity warnings.

6.4.8 Incorporate designs where crewmembers can temporarily relinquish critical procedures to automation when they feel GLOC approaching. Where the onset of loss of consciousness is sudden, the capability of the aircraft to detect an incapacitated aircrew and take over key functions is desirable.

6.4.9 Equipment to guard against the effects of high G's include full coverage anti-G trousers (FAGT's) and positive pressure breathing for G protection (PBG). If this equipment is implemented, cockpit designers should consider the crewmember limitations introduced by their use.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **6.0 Environmental Stressors** **Category:** **6.4 Acceleration/High G**

**References:**

Green, N. D. C., The Physiological Limitations of Man in the High G Environment, Combat Automation for Airborne Weapon Systems: Man/Machine Interface Trends and Technologies, AGARD Conference Proceedings 520, April 1993. (6.4.1, 6.4.2, 6.4.3, 6.4.4, 6.4.9)

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. I, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (6.4.5)

Lind, Judith H., Burge, Carol G., Human Factors Problems For Aircrew-Aircraft Interfaces: Where Should We Focus Our Efforts?, AGARD Conference Proceedings 521, October 1992. (6.4.6, 6.4.7, 6.4.8)

Sanders, M. S., McCormick, E. J., Human Factors in Engineering and Design, Seventh Edition, McGraw-Hill, Inc., 1993. (6.4.1)

Naval Air Development Center, Warminster, Pennsylvania, Human Performance Under High G Environments: A Comparison of Upright and Reclined Seat Configurations, (AD-A259 532). (6.4.3)

**Examples:**

6.4.1 This guideline argues for employment of Hands On Throttle And Stick (HOTAS) technology. For example, in one aircraft, the only control for ejection was placed where the crewmember had to reach over the head to operate it, precluding emergency egress from the aircraft in a high G situation.

6.4.2 If counteracting the effect of a heavy helmet is with a helmet support, care should be taken that head mobility is not restricted under normal conditions. The helmet support should also be compatible with emergency ejection from the aircraft.

6.4.3 Repositioning the crewmember into a prone or supine position while flying or implementing a rotating or tilting aircraft seat may alleviate this situation. This radical seat redesign should still allow unimpaired visibility of displays and flightpath, rapid location of necessary controls on easily operable hand grips, and safe and reliable emergency egress from the aircraft. Crewmembers should also be adequately trained in the redesigned cockpit.

[A study undertaken at NAWCAD Warminster compared pilot performance in an upright seat with two seats (Pelvis And Leg Elevating (PALE) seat and tilt back seat), that reclined at the onset of high G's. The study concluded that there were no significant improvements in performance with the reclining seats; however, lack of crewmember training in operating controls from the reclined position and engineering issues regarding the mechanization of the reclined seats may have contributed to these results.]

6.4.6 Implementation of displays with larger characters and increased contrast, or displays that adjust in high G situations are examples of this guideline. Insufficient data exist for determining exactly what the character size and contrast should be. Further tests are needed before conclusive recommendations can be made.

6.4.9 The use of FAGT's reduces lower body mobility as well as the amount of body area available for heat loss. The use of PBG above +7 Gz makes speech difficult and interferes with operating direct voice input (DVI) systems.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. These guidelines can be assessed through centrifuge testing. Although considerable testing has been performed investigating ways to improve crewmember physiological condition when exposed to high G's, little information is available in assessing aircrew performance in similar situations. Because centrifuge cockpit simulators are now available, testing aircrew performance under high G conditions should be conducted. (6.4.1 through 6.4.9)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 6.0 Environmental Stressors** **Category: 6.5 Fatigue**

**Rationale:**

Flight operations are often characterized by sustained mental and physical effort and prolonged vigilance which leads to fatigue. The nature of combat operations often requires many hours of mission planning and briefing by the same crewmembers who later fly into combat. This 'front-loading' of crewmembers during a period of continuous performance may last several hours to days and is only a prelude to the sustained performance required in the cockpit while actually flying the mission. Fatigue refers to a group of phenomena associated with the impairment or loss of efficiency and skill. Sleep deprivation is probably the major component contributing to operational fatigue in continuous work episodes during sustained operations. In the operational arena, fatigue may be considered a state of decreased performance resulting from an accumulation of the inherent stresses of military aviation. Fatigue may be caused by the following stressors:

- Sleep deprivation, deficit, or disruption.
- Work and rest schedules that result in circadian desynchronization.
- Enforced sitting posture and restriction of exercise during long hours of flight.
- Cockpit ergonomics and equipment discomfort.
- Thermal stress made worse by such things as chemical defense protective clothing.
- Noise and vibration.
- Motion sickness.
- Hypoxic environments, atmospheric pressure changes, humidity, and temperature differences.
- The effects of drugs such as caffeine, alcohol, antihistamines, etc.
- Problems with the excretion of waste, bladder distention, constipation, diarrhea, and gastrointestinal distention due to barometric pressure changes.
- Middle ear problems related to barometric pressure changes.
- Accelerative forces and G-related stress.
- Psychological stresses related to military aviation, sustained combat missions, and the interrelationships among these factors.

Fatigue can cause performance degradations such as mood and motivational changes, impaired attention, memory loss for recent events, variable and slowed responses, lack of insight on impaired performance, impaired task performance, and failure of interpersonal skills and crew coordination. Mental and physical "toughness," as well as prior experience with sleep loss, continue to be popular countermeasure myths. In fact, there appears to be no substitute for sleep itself.

Flying at night imposes a number of physiological challenges that are not present in comparable daytime operations.

Human circadian physiology creates a window of vulnerability for performance decrement around the time of the circadian temperature minimum, which is exacerbated when combined with sleep loss.

Fatigue effects are usually seen as a decline in alertness rather than in sensitivity. Tasks which show performance deterioration over time, such as continuous vigilance, tend to be repetitive and simple. When more complex tasks are studied, the effects of prolonged work are less direct, less uniform, and less specific in nature.

As fatigue increases, skilled subjects seem to lose the smooth coordination of the parts of the task, and attention is allocated less efficiently.

**Guidelines:**

6.5.1 Ensure sufficient motivation for the task. Sufficient motivation can temporarily overcome some fatigue effects, and real life experiences may generate higher motivation than experimental tasks.

6.5.2 Minimize sleep loss. Because the effects of sleep loss are cumulative, it is important not to begin a new work schedule with an existing sleep debt.

6.5.3 Plan controlled rest for low workload portions of the flight. Napping can be a preventive and/or countermeasure approach to fatigue. Generally, the longer the nap, the greater the benefits. Fatigue and sleep loss have been identified as important contributing factors in aviation incidents and accidents.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 6.0 Environmental Stressors** **Category: 6.5 Fatigue**

**References:**

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988. (6.5.1)

Rosekind, M. R., et al., Managing Fatigue in Operational Settings 1: Physiological Considerations and Countermeasures, Behavioral Medicine, Vol. 21, 1996. (6.5.2)

Gander, P. H., Nguyen, D., Rosekind, M., and Connell, L., Age, Circadian Rhythms, and Sleep Loss in Flight Crews, Aviation Space and Environmental Medicine, March 1993. (6.5.3)

Rosekind, M. R., Gander, P. H., Dinges, D. F., Alertness Management in Flight Operations: Strategic Napping, Aerospace Technology Conference and Exposition, Long Beach, California, 1991. (6.5.3)

**Example:**

6.5.1 The excitement of high tempo combat operations may temporarily lessen fatigue effects.

6.5.2 Scheduling of flight for crewmembers following a period of all night awake duty would be poor management practice.

6.5.3 Rest breaks on long duration flights on multicrewed aircraft (C-130, P-3) should be mandated.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. The effects of fatigue are well documented and should be considered in system design and operational doctrine. Use the NASA-Task Load Index (NASA-TLX) to assess subjective workload. (6.5.1, 6.5.2, 6.5.3)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 6.0 Environmental Stressors** **Category: 6.5 Fatigue**

**Guidelines (continued):**

6.5.4 Understand the two distinct components of sleepiness: physiological and subjective. Physiological sleepiness is the result of sleep loss. An accumulated sleep debt will be accompanied by physiological sleepiness that will drive an individual to sleep in order to meet the physiological need. Subjective sleepiness is an individual's introspective self-report regarding the level of sleepiness. An individual's subjective report of sleepiness can be affected by many factors, for example, caffeine, physical activity, and a particularly stimulating environment. However, an individual will typically report being more alert because of these factors. These factors can mask or conceal physiological sleepiness. This discrepancy between subjective and physiological sleepiness can be operationally significant. An individual may report a low level of sleepiness (i.e., high level of alertness) but be carrying an accumulated sleep debt with a high level of physiological sleepiness. This individual, in an environment stripped of factors that conceal the underlying physiological sleepiness, would be susceptible to the occurrence of spontaneous, uncontrolled sleep and the performance decrements associated with sleep loss.

6.5.5 Be aware of the following signs and symptoms of fatigue: forgetfulness, poor decision making, slowed reaction time, reduced vigilance, poor communication, fixation, apathy, lethargy, bad mood, and nodding off.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 6.0 Environmental Stressors** **Category: 6.5 Fatigue**

**References:**

Rosekind, M. R., et al., Alertness Management in Long-Haul Flight Operations, Proceedings of the Thirty-Ninth Corporate Aviation Safety Seminar, 1994. (6.5.4)

Rosekind, M. R., et al., Managing Fatigue in Operational Settings 1: Physiological Considerations and Countermeasures, Behavioral Medicine, Vol. 21, 1996. (6.5.5)

**Example:**

6.5.4 A crewmember might not "feel" sleepy, but could be suffering from a major sleep debt. Such a condition could cause the crewmember to be placed in a dangerous operational situation should she/he uncontrollably doze at the aircraft controls.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. The effects of fatigue are well documented and should be considered in system design and operational doctrine. Use the NASA-Task Load Index (NASA-TLX) to assess subjective workload. (6.5.4, 6.5.5)

THIS PAGE INTENTIONALLY LEFT BLANK

**Functional Area: 7.0 Advanced Technology**

7.1 Decision Aiding
7.2 Automation
7.3 Voice Interactive
7.4 Three-Dimensional Audio (3-D Audio)
7.5 Sensor/Data Fusion

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.1 Decision Aiding**

**Rationale:**

The challenge for the crewmember is cognitive, i.e., making inferences and deductions from incomplete and uncertain information derived from multiple sources and relating to several concurrent threats or potential threats under time compressed conditions. The cognitive functions performed by the crewmember are information and resource limited. Decisions are resource limited by the mental capacities of the crewmember, who must maintain large amounts of information in memory under conditions of high workload, uncertainty, time pressure, and environmental stressors. Decisions are also information limited by inability of sensors to provide error-free, unambiguous information to support the identification process. Decision aids should present information in a manner consistent with cognitive strategies that crewmembers naturally invoke. The human information processing system operates almost entirely serially, one process at a time, rather than in parallel fashion. This seriality is reflected in the narrowness of crewmember momentary focus of attention.

In complex and challenging domains, Naturalistic Decision Making (NDM) research revealed a number of findings that have implications for designing decision aiding systems, including:

- Crewmembers experiencing time pressure and other forms of stress rarely use analytical strategies based on probabilistic or weighing functions.
- Crewmembers usually satisfice (select the first option that meets minimal criteria for a set of features) rather than optimize.
- Diagnostic decisions are an important component of success in operational settings.
- Crewmembers use singular evaluations rather than comparative ones.
- Crewmembers invoke a variety of cognitive processes that are dependent on the function of the decision and the existing conditions.

Decision aids should be used to compensate for known limitations in human decision making and to offset the adverse effects of external factors. In general, difficulties arise because of fundamental limits of human cognitive (i.e., mental) abilities and lack of experience. Difficulties also arise because of various environmental factors that stress the crewmember and impact the type, quantity, quality, and rate of information presented. (Refer to Category 7.5.)

**Guidelines:**

**General Considerations**

7.1.1 Ensure the decision aid is easily used, provides beneficial information to the crewmember, and presents information that is readily understood and familiar to the crewmember. Ensure the decision aid sufficiently adjusts to crewmember task requirements.

- Reduce crewmember data-entry requirements as much as possible. Set crewmember modifiable defaults for data-entry fields.

7.1.2 Ensure the decision aid automatically alerts crewmembers to important new developments occurring in the database or as a result of predictive modeling.

7.1.3 Ensure the system encourages crewmember participation in the decision process.

7.1.4 Ensure the decision aid guides the crewmember through the analytical and decision processes. The decision aid should clearly indicate when crewmember input is required.

7.1.5 Avoid presenting too much data. Use aids to reduce, filter, and preprocess data into a useful form.

7.1.6 Avoid increasing crewmember workload. Point out the decision aid's abilities to increase effectiveness.

7.1.7 Reduce complexity. The system should provide no more information than is essential and should avoid repeating already available information. Present the information using a level of abstraction, resolution, or detail appropriate to the immediate task.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.1 Decision Aiding**

**References:**

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (7.1.1 through 7.1.7)

Adam, E. C., Tactical Cockpits-Flat Panel Imperatives, 1994. (7.1.4, 7.1.5, 7.1.6)

**Example:**

7.1.1 through 7.1.7 The system should represent problems and solutions in a manner familiar to crewmembers. The system should foster crewmember "ownership" of decisions and allow the crewmember to exercise judgment over the decision aid results, including providing the crewmember with sufficient information about the process and the result.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate decision aiding methods under typical cockpit environmental and operational conditions with a representative aircrew population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of decision aiding on workload. Use rating techniques such as SAGAT or SART to assess effects of decision aiding on Situational Awareness. (7.1.1 through 7.1.7)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.1 Decision Aiding**

**Guidelines (continued):**

**General Considerations (continued)**

7.1.8 Ensure the system anticipates crewmember needs and provides a degree of autonomous decision making.

7.1.9 Ensure crewmember capability to extend and personalize the decision aid. Provide means to validate crewmember created or modified models and provide sufficient warnings regarding failure to validate consequences. Ensure easy reversion to a default state.

7.1.10 Provide procedures appropriate to crewmember level of expertise. Designers should recognize that experts may use mental imagery; novices depend more on rule-based procedures.

**When to Use Decision Aids**

7.1.11 Use decision aids when the crewmember is trying to manipulate large amounts of data or visual representations, such as combining multiple criteria, allocating resources, managing detailed information, or selecting and deciding among alternatives.

7.1.12 Use decision aids when limited data result in uncertainty. Decision aids help by predicting future events from limited information, improving the accuracy and reliability of critical tasks, and addressing critical areas beyond crewmember ability.

7.1.13 Use decision aids to overcome human cognitive limitations such as dealing with uncertainty and overcoming emotional components of decision making. If the quality of human performance is in question, decision aids can add greater accuracy to the process. Decision aids are ideal in cases where memory and information-retention problems exist.

**When to Consider Alternatives**

7.1.14 Do not use decision aids when solutions are obvious or when one alternative clearly dominates all other options.

7.1.15 Use decision aids only when sufficient time is available or when the crewmember is authorized to make decisions.

**Cautions and Limitations**

7.1.16 Exercise caution when introducing decision aids that reduce the role of human judgment.

7.1.17 Take into account crewmember attitudes toward automation, which are often based on the fear of being replaced, when planning the role and degree of authority the crewmember will have in overriding automated decisions.

7.1.18 Develop decision aids that focus on tasks that crewmembers find difficult, rather than on what is routine.

**Decision Aid Requirements**

7.1.19 Base designs on an in-depth understanding of tasks to be performed and conditions of their performance:

- Decision aids must be matched to the situation and limitations they are designed to support.
- Recognize that not all functions are appropriate for decision aids. Determine the appropriate functions and design them to be compatible with crewmember decision processes.
- Provide no more than one aid for each task.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.1 Decision Aiding**

**References:**

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (7.1.8 through 7.1.19)

Harris, Steven D., Owens, J., Parisi, M., Becker, D., Sensor Fusion and Situation Assessment: A Perspective, 1991. (7.1.11, 7.1.12, 7.1.13)

**Example:**

7.1.12 The use of decision aiding to solve target ambiguity between intermittent radar and FLIR contacts is an example of this principle.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate decision aiding methods under typical cockpit environmental and operational conditions with a representative aircrew population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of decision aiding on workload. Use rating techniques such as SAGAT or SART to assess effects of decision aiding on Situational Awareness. (7.1.8 through 7.1.19)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** **Category:** 7.1 **Decision Aiding**

**Guidelines (continued):**

**Decision Aid Requirements (continued)**

7.1.20 Decision aid development should be driven by requirements, not by technology:

- Identify areas where crewmembers actually need help, then match the decision aid to their needs.
- Recognize crewmember decision situations and goals, and focus on the highest-level goal.
- Anticipate skepticism concerning automated decision support. Recognize that the dominant factor in accepting decision aids is perceived utility. The system must add new capabilities or increase efficiency in performance of decision-making tasks.
- Consider crewmember population characteristics in designing the decision aid and its interface.

**General Design Considerations**

7.1.21 Ensure decision aids are easier to use than the replaced decision process. They should be flexible, versatile, and easy enough to benefit typical crewmembers and should use terminology and criteria appropriate to the target crewmember group.

7.1.22 Ensure decision aids respond to crewmember ad hoc requests in time to allow the information to influence decisions. The interface should facilitate the exchange of information.

7.1.23 Tailor decision aids to crewmember resources.

7.1.24 Ensure decision aids automatically identify meaningful patterns and relationships and bring them to the crewmember's attention.

**Decision Alternatives**

7.1.25 Ensure decision aids support presentation, development, and evaluation of multiple alternatives. The decision aid should display which goals are served by different alternatives and options.

7.1.26 Ensure decision aids support crewmember evaluation of decision options. The decision aid should generate alternatives for crewmember evaluation and allow crewmember input of alternatives. The decision aid should have a method of assigning and explaining probabilities for alternatives. The crewmember should be able to explore different solutions, including different decision strategies and criteria.

**Prediction, Simulation, and Modeling**

7.1.27 Ensure the decision aid can predict future data. Historical data should be available to make comparisons, search for precedents, and assist crewmembers in visualizing trends. The decision aid should alert crewmembers when it predicts a future problem or opportunity upon which action is required.

7.1.28 Provide a modeling and simulation capability to support "what if?" exercises and to make predictions based on current conditions.

7.1.29 Ensure decision aiding models are appropriate, designed to answer specific questions, and validated.

**Decision Aid Interface**

7.1.30 Support intelligent dialogue between the crewmember and the decision aid.

7.1.31 Prevent crewmember errors. Provide automatic error recovery when errors are made.

7.1.32 Associate and group data in a meaningful way.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.1 Decision Aiding**

**References:**

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (7.1.20 through 7.1.32)

Halski, D. J., Landy, R. J., Kocher, J. A., Integrated Control and Avionics for Air Superiority: A Knowledge-Based Decision Aiding System, 1991. (7.1.23, 7.1.24)

**Example:**

7.1.21 through 7.1.24 Having the ability to quickly respond to a pop-up threat falls into this category.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate decision aiding methods under typical cockpit environmental and operational conditions with a representative aircrew population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of decision aiding on workload. Use rating techniques such as SAGAT or SART to assess effects of decision aiding on Situational Awareness. (7.1.20 through 7.1.32)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** **Category:** 7.1 **Decision Aiding**

**Guidelines (continued):**

**Training**

7.1.33 Provide appropriate crewmember training for tasks replaced by decision aids. Provide training to the crewmember in all required skills to maintain proficiency on backup systems. Training may be preferable to using decision aids for handling infrequent critical events occurring in dynamic environments.

7.1.34 Train crewmembers to recognize inappropriate uses of the aid, to recognize errors, and to not categorically accept a decision aid's capabilities.

**Decision Graphics and Displays**

7.1.35 Prepare graphics, textual reports, and input screens in formats familiar to the crewmember:

- Guard against inaccurate graphics, as they can have a strong negative impact.
- Provide historical displays of comparative cases, including time-sequenced presentations.
- Use spatial rather than textual formats when the task involves extensive spatial processing, particularly when task performance time is limited. Use tables rather than graphs when reading specific data points.

**Identify and Assess Factors Underlying Decisions**

7.1.36 Provide means to obtain and assess weights for multiple criteria. Multiple criteria should be statistically independent. Provide means to combine weights from multiple sources.

7.1.37 Identify and rank causal factors by their importance, and assign weights. The decision aid should allow crewmembers to modify decision factors and weights and to provide and adjust risk factors used in decision models.

7.1.38 Ensure decision aids explain underlying factors and support the use of sensitivity analysis. The decision aid should identify and assess operational constraints and inform the crewmember (upon request) of decision-aid boundaries or other limitations. Assumptions, underlying modes and parameters, and the decision aid's past performance history should be available to the crewmember.

7.1.39 Ensure easy crewmember input into the decision aid. Crewmembers should be able to add new decision factors and set the range of conditions, the level of output detail, and the parameters for optimization. Provide a means for saving and reusing the crewmember modifications and provide a means to return to the default settings.

7.1.40 Assist in visualizing interacting factors.

7.1.41 Provide a means for ensuring the validity of elements added to the decision model, in particular those used over successive applications.

**Flexibility**

7.1.42 Design decision aids as adaptive systems (i.e., they must accommodate growth and evolve over time to meet changing conditions, doctrine, etc.):

- Establish policies for implementing changes, as well as the mechanisms for those changes.
- Adjust to changing situations and crewmember preferences.
- Ensure the content and level of integration of information provided to the crewmember is appropriate for the functions and tasks being performed and the level of aiding or automation being used.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.1 Decision Aiding**

**References:**

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (7.1.33 through 7.1.42)

Hutchins, S. G., Principles for Intelligent Decision Aiding, Naval Postgraduate School, Monterey, California, 1995. (7.1.42)

**Example:**

7.1.35 Recommendations from the decision aiding system could take the form of a fly-to arrow depicting an evasive maneuver; an audio alert instructing the crewmember to "break left now;" or a flashing color highlighted table value of a recommended jamming frequency.

7.1.37 Weighted factors of a table could be displayed as color highlighted fields (red-high; yellow-medium; etc.)

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate decision aiding methods under typical cockpit environmental and operational conditions with a representative aircrew population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of decision aiding on workload. Use rating techniques such as SAGAT or SART to assess effects of decision aiding on Situational Awareness. (7.1.33 through 7.1.42)

## *SA IMPROVEMENT GUIDELINE*

| **Functional Area:** 7.0 **Advanced Technology** | **Category:** 7.1 **Decision Aiding** |
|---|---|

**Guidelines (continued):**

**Handling Decision Aid Recommendations**

7.1.43 Ensure the decision aid is able to calculate and display results of selected decision options.

7.1.44 Ensure the decision aid provides facilities for assessing costs, risks, and benefits of alternatives.

7.1.45 Ensure the decision aid explains the rationale behind outputs or recommendations and provides indicators of certainty or uncertainty when making recommendations.

7.1.46 Ensure the decision aid identifies missing or uncertain data and provides information on the impact of this data.

7.1.47 Ensure the decision aid includes internal consistency checks to prevent contradictory predictions and recommendations.

7.1.48 Ensure the decision aid informs the crewmember when it cannot handle the current situation.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.1 Decision Aiding**

**Reference:**

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994. (7.1.43 through 7.1.48)

**Example:**

7.1.48 An alert, such as "insufficient information for solution," presented when the decision aiding system cannot make a legitimate recommendation to the crewmember, is an example of this guideline.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate decision aiding methods under typical cockpit environmental and operational conditions with a representative aircrew population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of decision aiding on workload. Use rating techniques such as SAGAT or SART to assess effects of decision aiding on Situational Awareness. (7.1.43 through 7.1.48)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.2 Automation**

**Rationale:**

Cockpit automation has brought about a large number of techniques, mainly in ways in which aircrew employ the automatic devices and modes. These techniques are the result of the variety of ways to accomplish a task in a high-technology aircraft, due to its many modes and options. Automated systems are more complex and numerous, and often their inner functioning is partially or fully opaque to crewmembers. This increase in complexity raises crewmember concerns about automation trustworthiness and makes it difficult for them to be aware of all the intricacies of operation that may impact safe flight or successful mission accomplishment. Crewmembers are responsible for mission success, but cockpit tasks are widely distributed across human and automated resources. Advances in sensor and data integration technologies make more information available than may be prudent to present to crewmembers.

**Guidelines:**

7.2.1 Crewmembers should have final authority over critical flight functions and tasks.

7.2.2 Crewmembers should have access to information concerning the aircraft status, its systems, and the flight progress.

7.2.3 Crewmembers should have final authority over all dynamic functional and task allocation.

7.2.4 Crewmembers should have the authority to exceed known system limitations when necessary to maintain the safety of the flight.

7.2.5 Crewmembers should be appropriately involved in functions and tasks allocated to them.

7.2.6 A variety of strategies should be supported for meeting mission objectives.

7.2.7 The content and level of information integration provided to crewmembers should be appropriate for the functions and tasks performed and the level of aiding or automation used.

7.2.8 Methods for accomplishing flightcrew functions and tasks should be consistent with mission objectives.

7.2.9 Procedures and tasks with common components or goals should be performed in a consistent manner across systems and mission objectives.

7.2.10 Procedures and tasks with different components or goals should be distinct across systems and mission objectives.

7.2.11 The automated design should facilitate crewmember development of conceptual models of mission objectives and system functions that are both useful and consistent with reality.

7.2.12 Fundamental human limitations (e.g., memory, computation, attention, decision-making biases, task timesharing) should not be exceeded.

7.2.13 Fundamental human capabilities (e.g., problem solving, inductive reasoning) should be used to advantage.

7.2.14 Interference among functions or tasks which a crewmember may perform concurrently should be minimized.

7.2.15 Crewmember needs, humans in a potentially hazardous work environment, should be supported.

7.2.16 The automated design should accommodate what is known about basic human physical characteristics.

7.2.17 Peripheral activities, which are indirectly related to the mission objectives, should be supported.

7.2.18 The automated design should account for major cultural norms.

7.2.19 The automated design should facilitate crewmember awareness of their responsibilities, and the responsibilities of the other human operators and automated systems, in fulfilling the current mission objectives.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.2 Automation**

**Reference:**

Palmer, M. T., Rogers, W. H., Press, H. N., Latorella, K. A., Abbott, T. S., Summary of a Crew-Centered Flight Deck Design Philosophy for High-Speed Civil Transport (HSCT) Aircraft, NASA Langley Research Center, Hampton, Virginia, 1995. (7.2.1 through 7.2.19)

**Example:**

7.2.1, 7.2.3 Crewmembers should have the option to override and manually control an automated system, such as the automatic deployment of expendables (chaff, flares, decoys, munitions) from the aircraft.

7.2.15, 7.2.16 Automated systems should consider human physiological limitations, such as GLOC, and psychological limitations of long/short term memory, etc.

7.2.19 Automated systems should take into consideration other onboard and offboard systems such as AWACS, Air Traffic Control Systems, etc.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate automated systems under typical cockpit environmental and operational conditions with a representative crewmember population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of automation on workload. Use rating techniques such as SAGAT or SART to assess effects of automation methods on Situational Awareness. (7.2.1 through 7.2.19)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.2 Automation**

**Guidelines (continued):**

7.2.20 The automated design should facilitate communication of activities, task status, conceptual models, and current mission goals among crewmembers and the automated flight systems.

7.2.21 The automated design should support dynamic allocation of functions and tasks among multiple crewmembers and automated flight systems.

7.2.22 The automated design should ensure that team limitations are not exceeded.

7.2.23 Cooperative team capabilities (e.g., use of collective resources and cooperative problem solving) should be used to advantage when necessary.

7.2.24 The automated design should minimize interference among functions or tasks which may be performed concurrently by multiple aircrew or automated flight systems.

7.2.25 The automated design should facilitate prevention, tolerance, detection, and correction of both human and system errors, using capabilities of crewmembers and cockpit automation.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.2 Automation**

**Reference:**

Palmer, M. T., Rogers, W. H., Press, H. N., Latorella, K. A., Abbott, T. S., Summary of a Crew-Centered Flight Deck Design Philosophy for High-Speed Civil Transport (HSCT) Aircraft, NASA Langley Research Center, Hampton, Virginia, 1995. (7.2.20 through 7.2.25)

**Example:**

7.2.20 The automated system should, at all times, keep the crewmember team appraised of system status and system operating mode.

7.2.22, 7.2.23 The automated systems should be part of the functional mission team and not simply a stand-alone aircraft system.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate automated systems under typical cockpit environmental and operational conditions with a representative crewmember population. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of automation on workload. Use rating techniques such as SAGAT or SART to assess effects of automation methods on Situational Awareness. (7.2.20 through 7.2.25)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.3 Voice Interactive**

**Rationale:**

Interactive voice displays may supplement visual displays when communication flexibility is necessary, when coded signal meanings are numerous or may be forgotten, for presentation of complex directions or instructions, when ambient noise may mask simple tonal signals, or for presentation of continuous information where rate of change is low. The benefit of speech is that it is the most familiar way for humans to communicate. In the past, we interacted with machines in the language of the machines. With the advent of speech recognition and synthesis technology, humans can communicate with machines using constrained natural language.

Speech recognition systems are divided into two main categories: speaker-dependent systems which require a user to train the system to recognize his/her voice and speaker-independent systems which recognize any speaker in the language for which the system was designed. In general, speaker-dependent systems are more accurate. However, the trend is for speaker-independent systems which require little or no training time. A common complaint of voice interactive developers is that the design of every script (i.e., dialogue) constitutes a "nightmare" activity. Many of the problems experienced by applications developers are a result of poor human factors in the scripting or dialogue design. Other problems occur because the application chosen is ill-suited for implementation via Interactive Voice Response (IVR).

**Definitions:**

A speaker dependent system operates for a single speaker. These systems are usually easier to develop, cheaper to buy, and more accurate, but not as flexible as speaker adaptive or speaker independent systems.

A speaker independent system operates for any speaker of a particular type (e.g., American English). These systems are the most difficult and expensive to develop and accuracy is lower than speaker dependent systems. However, they are more flexible.

A speaker adaptive system adapts its operation to the characteristics of new speakers. Its difficulty lies somewhere between speaker independent and speaker dependent systems.

The size of vocabulary of a speech recognition system affects the complexity, processing requirements, and the accuracy of the system. Some applications only require a few words (e.g., numbers only); others require very large dictionaries. There are no established definitions, however, the following apply:

small vocabulary - tens of words
medium vocabulary - hundreds of words
large vocabulary - thousands of words
very large vocabulary - tens of thousands of words.

An isolated-word system operates on single words at a time - requiring a pause between saying each word. This is the simplest form of recognition to perform because the end points are easier to find and the pronunciation of a word tends not to affect others. Because the occurrences of words are more consistent, they are easier to recognize.

A continuous speech system operates on speech in which words are connected together, i.e., not separated by pauses. Continuous speech is more difficult to handle because of a variety of effects. First, it is difficult to find the start and end points of words. Another problem is "co-articulation." The production of each phoneme is affected by the production of surrounding phonemes, and, similarly, the start and end of words are affected by the preceding and following words. The recognition of continuous speech is also affected by the rate of speech (fast speech tends to be more difficult).

**Guidelines:**

7.3.1 Delegate the script writing function to a human factors engineer, familiar with crewmember operational and situational requirements, reflecting crewmember points of view. Scripts should not be derived directly from computer program flowcharts for the application.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** | **Category:** 7.3 **Voice Interactive**

**Reference:**

Gardner-Bonneau, D. J., Human Factors Problems in Interactive Voice Response (IVR) Applications: Do we need a Guideline/Standard?, Proceedings of the Human Factors and Ergonomics Society 36th Annual Meeting, 1992. (7.3.1)

**Example:**

7.3.1 Scripts should include operational language common to the specific aircrew community, such as "Fox 1."

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate voice interactive systems under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the interactive display is detectable. Check for background noises which may mask its intelligibility and perceptibility. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that the intended meaning of the voice interactive display is clear and immediately understood by the crewmember without ambiguity. (7.3.1)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.3 Voice Interactive**

**Guidelines (continued):**

7.3.2 The script developer should recognize crewmember training level.

7.3.3 Avoid lack of consistency or logic in the assignment of crewmember response options.

7.3.4 Avoid ambiguous language in the script.

7.3.5 Scripting should develop rapport with the crewmember.

7.3.6 Avoid inappropriate timing of prompts and timeouts.

7.3.7 Avoid requiring the crewmember to respond in ways which are awkward and unnatural.

7.3.8 Consider human memory and human information processing limitations of crewmembers.

7.3.9 Avoid poor or no error handling.

7.3.10 Avoid applications driven by technology requirements rather than by crewmember needs.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** **Category:** 7.3 **Voice Interactive**

**Reference:**

Gardner-Bonneau, D. J., Human Factors Problems in Interactive Voice Response (IVR) Applications: Do we need a Guideline/Standard?, Proceedings of the Human Factors and Ergonomics Society 36th Annual Meeting, 1992. (7.3.2 through 7.3.10)

**Example:**

7.3.2 A voice interactive system developed for the T-45 and used in the Naval Air Training Command would be different from that developed for the F/A-18E/F.

7.3.3 The use of the wording "Check #1 Engine Fuel Pressure" and "Advise #1 Engine Oil Pressure" are examples of lack of consistency.

7.3.4 "Hydraulic System" is ambiguous, whereas "#1 Hydraulic System Pressure Low" is not.

7.3.5 The scripting should not be annoying, irritating, or inappropriate.

7.3.8 Requiring the crewmember to repeat a long voice warning sequence verbatim to initiate corrective action is an example of this guideline.

**Method of Assessment:**

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate voice interactive systems under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the interactive display is detectable. Check for background noises which may mask its intelligibility and perceptibility. Measure with instrumentation and subjectively with crewmembers during program development. Ensure that the intended meaning of the voice interactive display is clear and immediately understood by the crewmember without ambiguity. (7.3.2 through 7.3.10)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** **Category:** 7.4 **Three-Dimensional Audio (3-D Audio)**

**Rationale:**

Three-Dimensional Auditory Technology (3-D Audio) is the manipulation of a sound signal in such a way as to give the illusion that the sound originates at a particular location in space. Adding a virtual location to an audio signal has the potential to enhance the quality of cockpit audio displays because it adds control and variety to the dimension of the sound. Most 3-D audio systems are actually two-dimensional, allowing crewmembers to observe only elevation and azimuth of a sound source, and assumes constant distance. 3-D audio has the potential to provide crewmembers with sounds that are either separated in space, or allocated to a specific location. Crewmembers operate in an environment where spatial cues are important. For 3-D audio to be effective in the cockpit, it must add value to the performance of the aircraft and its crew. Vertically localizable auditory cues may be useful for enhancing the spatial orientation of aircrew who are visually loaded and fail to maintain instrument scans (Endsley & Rosiles, 1995).

**Design Considerations:**

7.4.1 For sounds presented from points in a horizontal plane, the Minimum Audible Angle (MAA) is approximately 1 deg for sounds located directly in front of an observer. MAA increases as the reference sound moves to the listener's side. (MAA refers to the smallest angular difference between two successive sound sources needed for an observer to detect the sounds as coming from separate locations.)

7.4.2 Test results show that aircrew can more accurately judge the horizontal position of a sound than the elevation of a sound.

7.4.3 The addition of head movements improves auditory localization ability.

7.4.4 Aircrew have the ability to selectively listen to one of multiple, simultaneously presented auditory streams (commonly referred to the "Cocktail Party Effect").

7.4.5 If sounds are presented so that they appear to come from different virtual locations, the listener may be better able to choose the sounds they wish to attend.

7.4.6 Sound can be mapped to particular visual displays; sound can appear to come from a constant location; or sound can appear to come from the location of a process or object in space.

7.4.7 3-D audio can be incorporated using existing audio signals.

7.4.8 Presentation of information about objects or processes in space may only need to be accurate enough to direct the crewmember's attention to a fairly wide section of airspace.

7.4.9 Auditory spatial accuracy is generally highest at 90 and 270 deg, the points where interaural differences are maximized.

7.4.10 3-D sounds can be detected regardless of their position relative to the operator.

7.4.11 Aurally directed shifts to visual targets in the rear hemi-field can be acquired and identified in roughly the same time as unaided visual targets appearing within a few degrees of the crewmember's fovea.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** **7.0 Advanced Technology** **Category:** **7.4 Three-Dimensional Audio (3-D Audio)**

**References:**

Lee, M. D., Patterson, R. W., The Application of Three-Dimensional Auditory Displays to Aircraft Cockpits: User Requirements, Technology Assessment, and Operational Recommendations, Lockheed Aeronautical Systems Company, 1993. (7.4.1, 7.4.2, 7.4.3, 7.4.4, 7.4.5, 7.4.6, 7.4.7, 7.4.8, 7.4.9)

McKinley, R. L., D'Angelo, W. R., Perrot, D. R., Cisneros, J., Aurally Aided Detection and Identification of Visual Targets, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995. (7.4.10, 7.4.11)

**Example:**

7.4.1 A reference sound is played directly in front of an observer (the audio display device is shielded from view). A second sound is then displayed slightly to the left or right of the reference sound. The observer then decides whether the two sounds came from the same or different locations.

7.4.2 Calling traffic at "12 o'clock high" via 3-D audio may not be as accurate in elevation as a call of traffic at "2 o'clock level". This is due to the lack of vertical displacement of the ears.

7.4.3 When the head moves, cues that help perceptive location are modulated, depending upon the location of the sound and changes in the listener's head position.

7.4.4, 7.4.5 3-D audio can be used to spatially separate incoming radio channels, helping the crewmember to devote attention to the communications channel of choice.

7.4.6 Sound is mapped to a fuel control panel to alert the crewmember to a fuel system malfunction; sound appears to come from a constant location as if it were the voice of the airplane; sound appears to come from the location of another aircraft or a missile.

7.4.7 Existing warning/caution/advisory tones can be mapped to the appropriate display. Threat warning tones can be incorporated into 3-D directional cueing.

7.4.8 Calling traffic at "2 o'clock" in reality denotes a 30 deg sector of airspace.

7.4.9 3-D audio advising of an approaching missile at 9 o'clock should provide greater accuracy than a call at 1 o'clock.

7.4.10 Reduction in the time required to locate and identify a "patch" of visual information should be substantial for all regions around the operator.

7.4.11 An aurally directed shift in gaze advises the crewmember of an incoming threat at 5 o'clock.

**Method of Assessment:**

Develop a checklist based on applicable design considerations and evaluate system design. Compare design with functional requirements. Evaluate 3-D audio systems under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the auditory coding is detectable. Check for background noises which mask perceptibility. Signals with different meanings should not sound identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Measure the angular accuracy of 3-D audio signals. (7.4.1 through 7.4.11)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** **Category:** 7.4 **Three-Dimensional Audio (3-D Audio)**

**Design Considerations (continued):**

7.4.12 Binaural listening allows a crewmember to use head-shadow and binaural interaction advantages simultaneously for signal against noise intelligibility, which translates into about a 6 dB improvement in intelligibility.

7.4.13 Auditory spatial cues are more effective than abrupt visual onsets when the target appears in the peripheral visual field or when the target contrast is degraded.

7.4.14 Auditory spatial cue effectiveness is most pronounced in restricted Field-Of-View (FOV) visual conditions, which are commonly encountered in Helmet Mounted Display (HMD) applications.

**Guidelines**

7.4.15 Use multidimensional cues to improve auditory vertical plane localization.

7.4.16 Use audio localization to enhance crewmember speed and accuracy in responding to audible alerting signals.

## *SA IMPROVEMENT GUIDELINE*

**Functional Area:** 7.0 **Advanced Technology** **Category:** 7.4 **Three-Dimensional Audio (3-D Audio)**

**References:**

Begault, D. R., Head-Up Auditory Display Research at NASA Ames Research Center, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995. (7.4.12)

Endsley, M. R., Rosiles, S. A., Vertical Auditory Localization for Spatial Orientation, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995. (7.4.15)

McKinley, R. L., D'Angelo, W. R., Haas, M. W., Perrot, D. R., Nelson, W. T., Hettinger, L. J., Brickman, B. J., An Initial Study of the Effects of 3-Dimensional Auditory Cueing on Visual Target Detection, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995. (7.3.14)

Strybel, T. Z., Boucher, J. M., Fujawa, G. E., Volp, C. S., Auditory Spatial Cueing Visual Search Tasks: Effects of Amplitude, Contrast and Duration, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995. (7.4.13)

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995. (7.4.16)

**Example:**

7.4.12 Binaural listening, assisting the crewmember to more clearly understand radio/ICS transmissions in a noise cluttered environment, is an example.

7.4.13 If a visual target is presented in an otherwise empty field, search times are reduced by the use of auditory spatial cues.

7.4.14 Auditory cues would decrease search times for targets/objects outside the HMD FOV.

7.4.15 Since auditory localization in the vertical plane is vastly inferior to localization in the horizontal plane, the addition of supplementary cues (such as frequency changes) will improve vertical plane localization performance.

**Method of Assessment:**

Develop a checklist based on applicable design considerations/guidelines and evaluate system design. Compare design with functional requirements. Evaluate 3-D audio systems under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure that the auditory coding is detectable. Check for background noises which mask perceptibility. Signals with different meanings should not sound identical. Ensure that the intended meaning of the signal is clear and immediately understood by the crewmember without ambiguity. Measure the angular accuracy of 3-D audio signals. (7.4.12 through 7.4.15)

## *SA IMPROVEMENT GUIDELINE*

**Functional Area: 7.0 Advanced Technology** **Category: 7.5 Sensor/Data Fusion**

**Rationale:**

Still in its infancy and emerging as a means to improve situational awareness, sensor/data fusion is the integration or merging of data from multiple sensors to enhance sensor viewing resolution and accuracy. Because of the importance of information obtained from intelligence fusion, the need to increase knowledge regarding authentic threats will expand dramatically in the future. Multispectral sensor fusion techniques can be used to solve a variety of classification and discrimination problems. Much current threat data already exists, however, objective evaluation of this data is almost impossible without an integrated, unified approach to develop tactical information.

Every opportunity a sensor has to sample the environment equates to a certain amount of data which can be obtained about the state of that environment. A fundamental question is how to use this potential information to manage a suite of sensors while maximizing the net knowledge about the state of the environment. Bayesian networks show great promise for recognizing targets from observed data since they can be used to represent complicated probabilistic relationships among variables of interest.

**Design Considerations:**

7.5.1 The fusion process should be highly flexible in the nature as well as the number of inputs. The main inputs available to the fusion processor are the confidence factors corresponding to the different algorithms in the specific fusion context. The output is the fused system confidence in the detection, which can be appropriately thresholded or directly employed for target prioritization.

7.5.2 View decision systems as having two distinct phases:

- A learning phase, during which the system develops the capability to distinguish different target classes and clutter present in the environment.
- An operational decision phase, a sequel to the learning phase, in which individual decisions from different processes being input to the system are fused to identify the object as belonging to a known target class.

7.5.3 It is essential to provide for continued learning during the operational decision phase, and to update fusion system characteristics when additional learning is carried out by the system.

7.5.4 Do not necessarily consider the radar measurement and imaging sensor measurement to be the same point in the fusion of radar and imaging sensor data. The distinction between the radar and imaging sensor measurements becomes particularly important for systems which fuse data from different sensors, since assuming that data from two sensors are measuring the same target point can cause the fused estimate to be worse than the estimate produced by a single sensor system.

7.5.5 Use sensor fusion to aid human decision making under time constraints by integrating large amounts of sensor data into a few meaningful results.

7.5.6 The fusion of passive infrared data with radar data in combat systems requires compatible range and bearing information.

7.5.7 Ensure data association confidently correlates multiple sensor measurements to ascertain that they correspond to a common data set. Poor data association performance results in misassociation and misidentification by the sensor fusion system.

7.5.8 Target orientation, which impacts target radar cross section, is an important factor that greatly affects target recognition.

7.5.9 Data fusion processing must be feasible within the framework of the overall parent information processing architecture, and usually requires an integrated architecture.

## *SA IMPROVEMENT GUIDELINE*

| | |
|---|---|
| **Functional Area: 7.0 Advanced Technology** | **Category: 7.5 Sensor/Data Fusion** |

**References:**

Dasarathy, Belur V., Adaptive Fusion Processor Paradigms for Fusion of Information Acquired at Different Levels of Detail, Optical Engineering, Vol. 35, No. 3, March 1996. (7.5.1, 7.5.2, 7.5.3)

Romine, J. B., and Kamen, E. W., Modeling and Fusion of Radar and Imaging Sensor Data for Target Tracking, Optical Engineering, Vol. 35, No. 3, March 1996. (7.5.4)

Maheshkumar, J. R., Veeranna, V., Iyengar, S. S., Brooks, R. R., New Computational Technique for Complementary Sensor Integration in Detection-Localization Systems, Optical Engineering, Vol. 35, No. 3, March 1996. (7.5.5)

Pieper, R. J., Cooper, A. W., Pelegris, G., Passive Range Estimation using Dual-baseline Triangulation, Optical Engineering, Vol. 35, No. 3, March 1996. (7.5.6)

Leung, H., Neural Network Data Association with Application to Multiple-Target Tracking, Optical Engineering, Vol. 35, No. 3, March 1996. (7.5.7)

Liu, J., Chang, K. C., Feature-Based Target Recognition with a Bayesian Network, Optical Engineering, Vol. 35, No. 3, March 1996. (7.5.8)

Keene, A. P., Perre, M., Data Fusion: A Preliminary Study, TNO Physics and Electronics Laboratory, December 1990. (7.5.1 through 7.5.8)

Llinas, J., Beale, G., Hintz, K., JDL Real Time Sensor Control Study RL-TR-92-270, Rome Laboratory, December 1992. (7.5.9)

**Example:**

7.5.1 Other information, such as target height, width, frequency, and velocity, may be effectively used by expanding the decision space.

7.5.4 The radar centroid and the "hot spot" of a thermal image may not coincide.

7.5.5 The fusing of radar, IR, optical, and passive RF sensors with an intelligence data base to provide warning of a missile launch is an example of this design consideration.

7.5.7 Two uncorrelated targets, one radar, one IR, in close proximity to each other, causing data association problems, is an example of this principle.

**Method of Assessment:**

Develop a checklist based on applicable design considerations and evaluate system design. Compare design with functional requirements. Evaluate sensor fusion design considerations under typical cockpit environmental and operational conditions with a representative crewmember population. Ensure accuracy by evaluating sensor fusion algorithms against baseline threat parameters. Use assessment techniques such as the NASA-Task Load Index (NASA-TLX) to determine the effects of decision aiding on workload. Use rating techniques such as SAGAT or SART to assess effects of decision aiding on Situational Awareness. (7.5.1 through 7.5.9)

THIS PAGE INTENTIONALLY LEFT BLANK

**Guideline References**

Adam, E. C., Tactical Cockpits-Flat Panel Imperatives, 1994.

Begault, D. R., Head-Up Auditory Display Research at NASA Ames Research Center, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995.

Beilman, J. L. and Gawron, V. J., Guidelines for Using Airborne Color Displays, 1985.

Bell, P., Fisher, J., Baum, A., and Greene, T., Environmental Psychology, Fort Worth: Holt, Rinehart and Winston, Inc., Third Edition, 1990.

Best, P. S., Schopper, A. W., Effects of System Delay on Aviator-Related Performance, CSERIAC-RA-95-011, 1995.

Boff, K. R., Lincoln, J. E., Engineering Data Compendium; Human Perception and Performance, VOL. 1, Harry G. Armstrong Aerospace Medical Research Laboratory, 1988.

Crvarich, G., An Exploration of Techniques to Improve Relative Distance Judgments within an Exocentric Display, 1995.

Dasarathy, Belur V., Adaptive Fusion Processor Paradigms for Fusion of Information Acquired at Different Levels of Detail, Optical Engineering, Vol. 35, No. 3, March 1996.

Defense Information Systems Agency (DISA), User Interface Specifications For The Defense Information Infrastructure (DII), Version 2.0 Preliminary Draft, December 31, 1995.

Defense Information Systems Agency Center for Architecture, Department Of Defense Technical Architecture Framework For Information Management Volume 8: Department of Defense Human Computer Interface (HCI) Style Guide, 30 June 1994.

Defense Information Systems Agency, User Interface Specifications for the Global Command and Control System (GCCS) Version 1.0, October 1994.

Department of Defense Handbook, Human Engineering Guidelines for Management Information Systems, MIL-HDBK-761A, 1989.

Endsley, M. R., Rosiles, S. A., Vertical Auditory Localization for Spatial Orientation, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995.

Gander, P. H., Nguyen, D., Rosekind, M., and Connell, L. Age, Circadian Rhythms, and Sleep Loss in Flight Crews, Aviation Space and Environmental Medicine, March 1993.

Gardner-Bonneau, D. J., Human Factors Problems in Interactive Voice Response (IVR) Applications: Do we need a Guideline/Standard?, Proceedings of the Human Factors and Ergonomics Society 36th Annual Meeting, 1992.

Gawron, V. J., Bailey, R. E., Knotts, L. H., McMillan, G. R., Comparison of Time Delay during In-Flight and Ground Simulation, Proceedings of the Human Factors Society 33rd Annual Meeting, 1989.

Gilmore, W. E., Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, Idaho Falls, Idaho: E G & G Idaho, Inc., July 1985.

Goddard Space Flight Center, Data Systems Technology Division Software and Automation Systems Branch / Code 522, Human-Computer Interface Guidelines, Carlow International Incorporated, Falls Church, Virginia, 1992.

Green, N. D. C., The Physiological Limitations of Man in the High G Environment, Combat Automation for Airborne Weapon Systems: Man/Machine Interface Trends and Technologies, AGARD Conference Proceedings 520, April 1993.

Halski, D. J., Landy, R. J., Kocher, J. A., Integrated Control and Avionics for Air Superiority: A Knowledge-Based Decision Aiding System, 1991.

Hancock, P. A., Sustained Attention Under Thermal Stress, American Psychological Association, Inc. Bulletin, Vol. 99, No. 2, 1986.

Hancock, P. A., Task Categorization and the Limits of Human Performance in Extreme Heat, Motor Behavior Laboratory, University of Illinois at Urbana-Champaign, Champaign, Illinois, 1982.

Harris, Steven D., Owens, J., Parisi, M., Becker, D., Sensor Fusion and Situation Assessment: A Perspective, 1991.

Harrison, J., Janowitz, J., Castronuovo, M., Pilot-Vehicle Interface, Federal Aviation Administration, DOT/FAA/CT-92/21, 1993.

Hutchins, S. G., Principles for Intelligent Decision Aiding, Naval Postgraduate School, Monterey, California, 1995.

Johns, J. B., Funk, J. D., Impact of V-22 Display Latency on Flying Qualities, Warminster, Pennsylvania: Naval Air Development Center, DTIC No. AD-B161 084, 1991.

Keene, A. P., Perre, M., Data Fusion: A Preliminary Study, TNO Physics and Electronics Laboratory, December 1990.

Lee, M. D., Patterson, R. W., The Application of Three-Dimensional Auditory Displays to Aircraft Cockpits: User Requirements, Technology Assessment, and Operational Recommendations, Lockheed Aeronautical Systems Company, 1993.

Leung, H., Neural Network Data Association with Application to Multiple-Target Tracking, Optical Engineering, Vol. 35, No. 3, March 1996.

Lind, Judith H., Burge, Carol G., Human Factors Problems For Aircrew-Aircraft Interfaces: Where Should We Focus Our Efforts?, AGARD Conference Proceedings 521, October 1992.

Liu, J., Chang, K. C., Feature-Based Target Recognition with a Bayesian Network, Optical Engineering, Vol. 35, No. 3, March 1996.

Llinas, J., Beale, G., Hintz, K., JDL Real Time Sensor Control Study RL-TR-92-270, Rome Laboratory, December 1992.

Lockhart, J. M., Kiess, H. O., and Clegg, T. J., Effect of Rate and Level of Lowered Finger Surface Temperature on Manual Performance, Journal of Applied Psychology, 1975.

Lynch, P. J., Graphics in the Interface, Yale Center for Advanced Instructional Media, Journal of Biocommunications, 1994.

Maheshkumar, J. R., Veeranna, V., Iyengar, S. S., Brooks, R. R., New Computational Technique for Complementary Sensor Integration in Detection-Localization Systems, Optical Engineering, Vol. 35, No. 3, March 1996.

McKinley, R. L., D'Angelo, W. R., Haas, M. W., Perrot, D. R., Nelson, W. T., Hettinger, L. J., Brickman, B. J., An Initial Study of the Effects of 3-Dimensional Auditory Cueing on Visual Target Detection, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995.

McKinley, R. L., D'Angelo, W. R., Perrot, D. R., Cisneros, J., Aurally Aided Detection and Identification of Visual Targets, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995.

McKinley, R. L., Erikson, M. A., D'Angelo, W. R., 3-Dimensional Auditory Displays: Development, Applications, and Performance, Aviation, Space and Environmental Medicine, 1994.

Mlnarik, R., Daily Flight Report: Compatibility of CBR Gear in the AV-8B, NAWC-AD, Patuxent River, Maryland, 10 October 1995.

Naval Air Development Center, Warminster, Pennsylvania, Human Performance Under High G Environments: A Comparison of Upright and Reclined Seat Configurations, (AD-A259 532).

Naval Air Technical Services Facility, Aircrew Personal Protective Equipment, Technical Manual for Aviation-Crew Systems, Philadelphia, Pennsylvania.

Palmer, M. T., Rogers, W. H., Press, H. N., Latorella, K. A., Abbott, T. S., Summary of a Crew-Centered Flight Deck Design Philosophy for High-Speed Civil Transport (HSCT) Aircraft, NASA Langley Research Center, Hampton, Virginia, 1995.

Pieper, R. J., Cooper, A. W., Pelegris, G., Passive Range Estimation using Dual-baseline Triangulation, Optical Engineering, Vol. 35, No. 3, March 1996.

Ripley, Grady L., Solana, Kathy E., Hill, Ronald C., Female Anti-G Suit Fit and Comfort, SAFE Journal, Vol. 24, No. 2.

Romine, J. B., and Kamen, E. W., Modeling and Fusion of Radar and Imaging Sensor Data for Target Tracking, Optical Engineering, Vol. 35, No. 3, March 1996.

Rosekind, M. R., et al., Alertness Management in Long-Haul Flight Operations, Proceedings of the Thirty-Ninth Corporate Aviation Safety Seminar, 1994.

Rosekind, M. R., et al., Managing Fatigue in Operational Settings 1: Physiological Considerations and Countermeasures, Behavioral Medicine, Vol. 21, 1996.

Rosekind, M. R., Gander, P. H., Dinges, D. F., Alertness Management in Flight Operations: Strategic Napping, Aerospace Technology Conference and Exposition, Long Beach, California, 1991.

Rubin, L. S., Manual Dexterity of the Gloved and Bare Hand as a Function of the Ambient Temperature and Duration of Exposure, Journal of Applied Psychology, 1957.

Sanders, M. S., McCormick, E. J., Human Factors in Engineering and Design, Seventh Edition, McGraw-Hill, Inc., 1993.

Smith, S. L., Mosier, J. N., Guidelines For Designing User Interface Software (ESD-TR-86-278), The MITRE Corporation, Bedford, Massachusetts, USA, 1986.

So, R. H. Y., Griffin, M. J., Effect of Lags on Human Performance with Head-Coupled Simulators, Wright-Patterson Air Force Base, OH: Air Force Material Command, DTIC No. AD-A279 577, 1993.

Strybel, T. Z., Boucher, J. M., Fujawa, G. E., Volp, C. S., Auditory Spatial Cueing Visual Search Tasks: Effects of Amplitude, Contrast and Duration, Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, 1995.

Teichner, W. H. and Kobrick, J. L., Effects of Prolonged Exposure to Low Temperature on Visual-Motor Performance, Journal of Experimental Psychology, 1955.

U.S. Department of Defense, Aircrew Station Alerting Systems, MIL-STD-411F (Draft), 20 January 1995.

U.S. Department of Defense, Flying Qualities of Piloted Airplanes, MIL-F-8785C, 1980.

U.S. Department of Defense, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472D, 14 March 1989, Notice 1 and 2 Incorporated.

U.S. Department of Defense, Common Warfighting Symbology, Version 1, MIL-STD-2525, 30 September 1994.

U.S. Nuclear Regulatory Commission, Advanced Human-System Interface Design Review Guideline, NUREG/CR-5908, Vol. 2, July 1994.

U.S. Nuclear Regulatory Commission, Human Engineering Guidelines for the Evaluation and Assessment of Video Display Units, NUREG/CR-422, July 1985.

Woodson, W. E., Human Factors Design Handbook, New York: McGraw-Hill, 1981.

Zhang, K., Wickens, C. D., Effects of Noise and Workload on Performance With Two Object Displays vs. A Separated Display, Proceedings of the Human Factors Society 34th Annual Meeting, 1990.

THIS PAGE INTENTIONALLY LEFT BLANK

DISTRIBUTION:

| | |
|---|---|
| ASN RD&A (PEO(T)) | (1) |
| ASN RD&A (PEO(A)) | (1) |
| ASN RD&A (PEO(CU)) | (1) |
| ASN RD&A (PEO(CU)CT) | (1) |
| ASN RD&A (PEO(CU)U) | (1) |
| ASN RD&A (PEO(CU)UD) | (1) |
| ASN RD&A (PEO(CU)UT) | (1) |
| ASN RD&A (PEO(CU)AQ) | (1) |
| ASN RD&A (PEO(T) (PMA-201)) | (1) |
| ASN RD&A (PEO(T) (PMA-231)) | (1) |
| ASN RD&A (PEO(T) (PMA-233)) | (1) |
| ASN RD&A (PEO(T) (PMA-234)) | (1) |
| ASN RD&A (PEO(T) (PMA-241)) | (1) |
| ASN RD&A (PEO(T) (PMA-242)) | (1) |
| ASN RD&A (PEO(T) (PMA-259)) | (1) |
| ASN RD&A (PEO(T) (PMA-265)) | (1) |
| ASN RD&A (PEO(T) (PMA-272)) | (1) |
| ASN RD&A (PEO(A) (PMA-257)) | (1) |
| ASN RD&A (PEO(A) (PMA-261)) | (1) |
| ASN RD&A (PEO(A) (PMA-264)) | (1) |
| ASN RD&A (PEO(A) (PMA-271)) | (1) |
| ASN RD&A (PEO(A) (PMA-273)) | (1) |
| ASN RD&A (PEO(A) (PMA-275)) | (1) |
| ASN RD&A (PEO(A) (PMA-276)) | (1) |
| ASN RD&A (PEO(A) (PMA-290)) | (1) |
| ASN RD&A (PEO(A) (PMA-299)) | (1) |
| ASN RD&A (PEO(CU) (PMA-263)) | (1) |
| NAVAIRSYSCOM (PMA-200) | (1) |
| NAVAIRSYSCOM (PMA-202) | (1) |
| NAVAIRSYSCOM (PMA-205) | (1) |
| NAVAIRSYSCOM (PMA-209) | (1) |
| NAVAIRSYSCOM (PMA-213) | (1) |
| NAVAIRSYSCOM (PMJ01) | (1) |
| NAVAIRSYSCOM (AIR-1.0) | (1) |
| NAVAIRSYSCOM (AIR-2.0B) | (1) |
| NAVAIRSYSCOM (AIR-4.0) | (1) |
| NAVAIRSYSCOM (AIR-4.0A) | (1) |
| NAVAIRSYSCOM (AIR-4.0B) | (1) |
| NAVAIRSYSCOM (AIR-4.0C) | (1) |
| NAVAIRSYSCOM (AIR-4.0T) | (1) |
| NAVAIRSYSCOM (AIR-4.1) | (1) |
| NAVAIRSYSCOM (AIR-4.5) | (1) |
| NAVAIRSYSCOM (AIR-4.6) | (1) |

| | |
|---|---|
| NTIS | (1) |
| CSERIAC | (1) |
| U.S. Army Natick RD&E Center (SSCNC-YBH), Natick, MA | (2) |
| Wright Laboratory (WL/AA), Wright-Patterson AFB, OH | (2) |
| Wright Laboratory (WL/FIGP-1), Wright-Patterson AFB, OH | (2) |
| Armstrong Laboratory (AL/DFTO), Brooks AFB, TX | (2) |
| Armstrong Laboratory (AL/CFHP), Wright-Patterson AFB, OH | (2) |
| NAVTESTWINGLANT Patuxent River, MD (55TW01A) | (1) |
| NAVAIRWARCENACDIV Patuxent River, MD (4.6.1.4) | (400) |
| NAVAIRWARCENACDIV Patuxent River, MD (Technical Publishing Team) | (1) |
| DTIC | (1) |